(NASA-CR-150017) PHASE B-FINAL DEFINITION AND PRELIMINARY DESIGN STUDY FOR THE INITIAL ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL). A SPACELAB MISSION PAYLOAD Interim Report (TRW Systems Group) 289 p HC $9.25 CSCL 22B G3/18

N76-33273

Unclas 05718

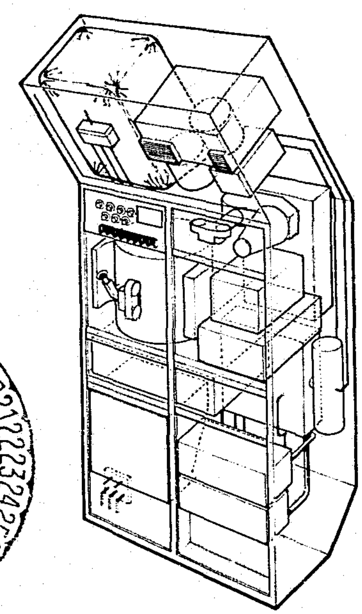
CONTRACT NAS8-31844

PHASE B-FINAL DEFINITION AND PRELIMINARY DESIGN STUDY FOR THE INITIAL ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL) - A Spacelab Mission Payload

INTERIM REVIEW (DR-MA-03)

SEPTEMBER 23, 1976

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812



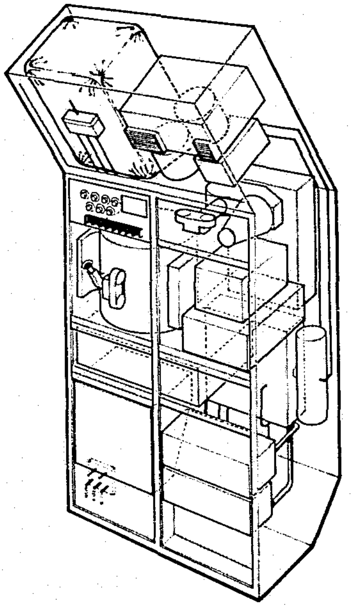
By
ACPL PROGRAM TEAM
O.W. Clausen, Program Manager

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278

CONTRACT NAS8-31844

PHASE B-FINAL DEFINITION AND PRELIMINARY DESIGN STUDY FOR THE INITIAL ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL) - A Spacelab Mission Payload

INTERIM REVIEW (DR-MA-03)



SEPTEMBER 23, 1976

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

By
ACPL PROGRAM TEAM
O.W. Clausen, Program Manager

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278

AGENDA

NASA REMARKS		09:00 - 09:10
I.	SUMMARY – PROGRAM STATUS	09:10 - 09:30
II.	TECHNICAL DISCUSSION – PRELIMINARY DESIGN	
	A) EXPERIMENTAL CHAMBERS	09:30 - 11:45
	B) SCIENTIFIC SUBSYSTEMS	01:00 - 01:30
	C) SUPPORT SUBSYSTEMS	01:30 - 03:30
III.	PHASE C/D PROGRAM PLANNING	03:30 - 03:45
IV.	WRAP-UP	03:45 - 04:00

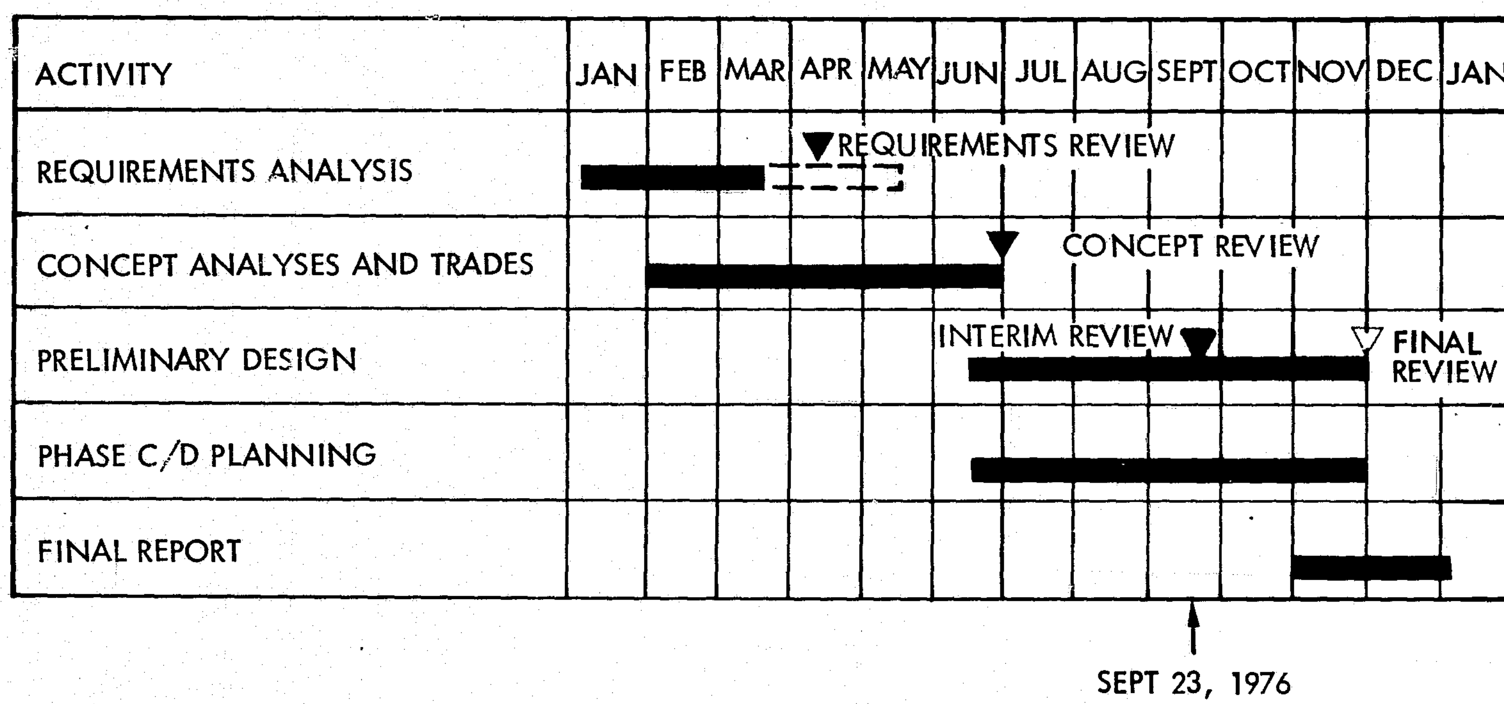
TRW
SYSTEMS GROUP

SUMMARY - PROGRAM STATUS

BILL CLAUSEN

The facing page represents an overview for the ACPL Phase B Study. The effort has been underway approximately 37 weeks; there are 11 weeks left to Final Review and 16 weeks left to contract completion.

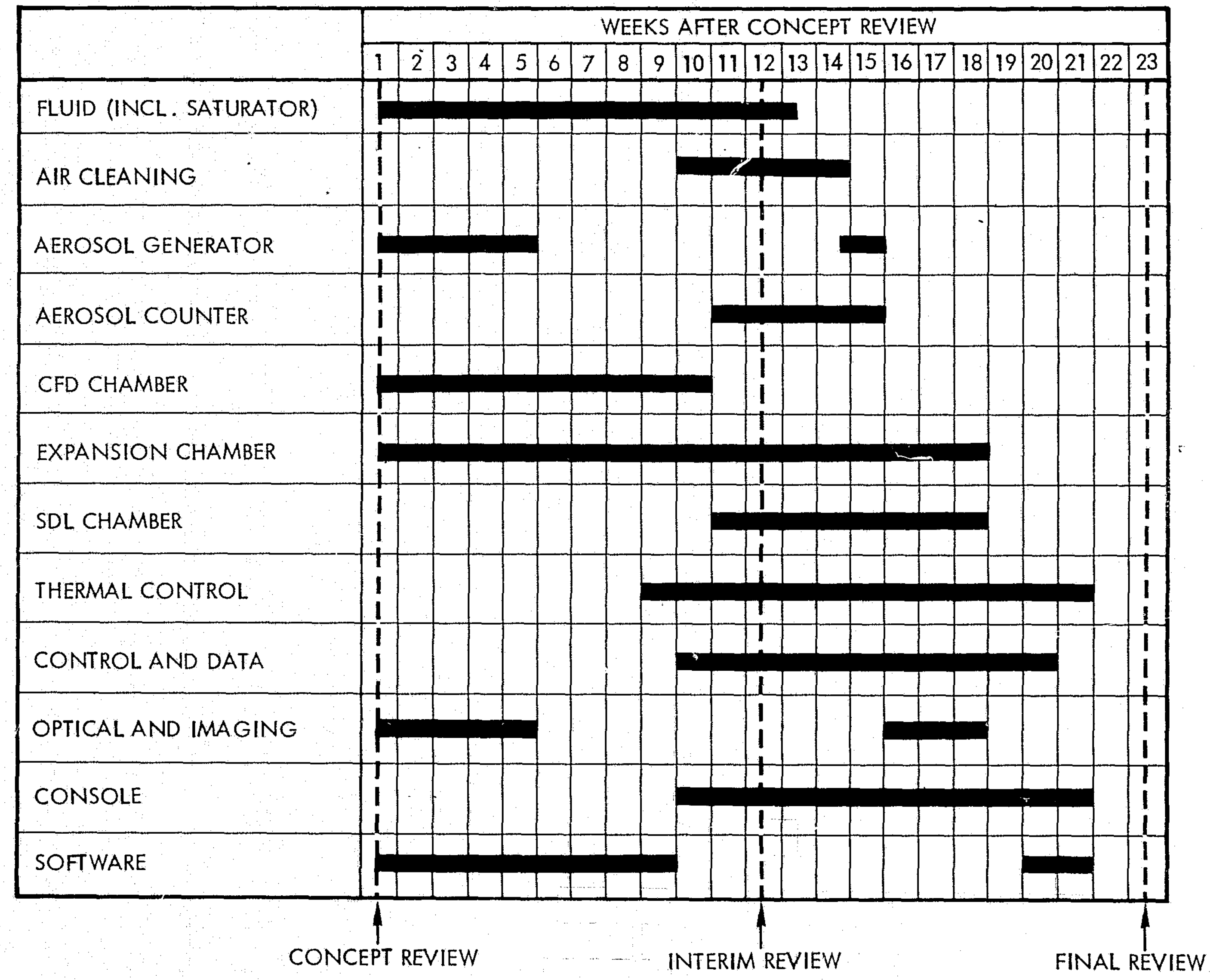
ACPL PROGRAM SCHEDULE



TRW

The schedule of preliminary design activity for each of the individual laboratory elements is shown on the facing page. Five elements (Fluid System, Saturator, Aerosol Generator, CFD and Software) are essentially complete and will be reported in detail in this package. A substantial amount of attention has also been given to the Expansion Chamber. This work is not complete; its status will be reported. Preliminary design effort on other subsystem elements (Aerosol Counter, SDL, Thermal Control, Control and Data, Optical and Imaging, and Console) has just been initiated; these elements will not be discussed here except to present specific data of interest.

ACPL SUBSYSTEM PRELIMINARY DESIGN SCHEDULE



TRW SYSTEMS GROUP

The facing page highlights the major features of the preliminary design effort to date in a number of key subsystems. Each of these features will be discussed in detail in the appropriate sections of this briefing package.

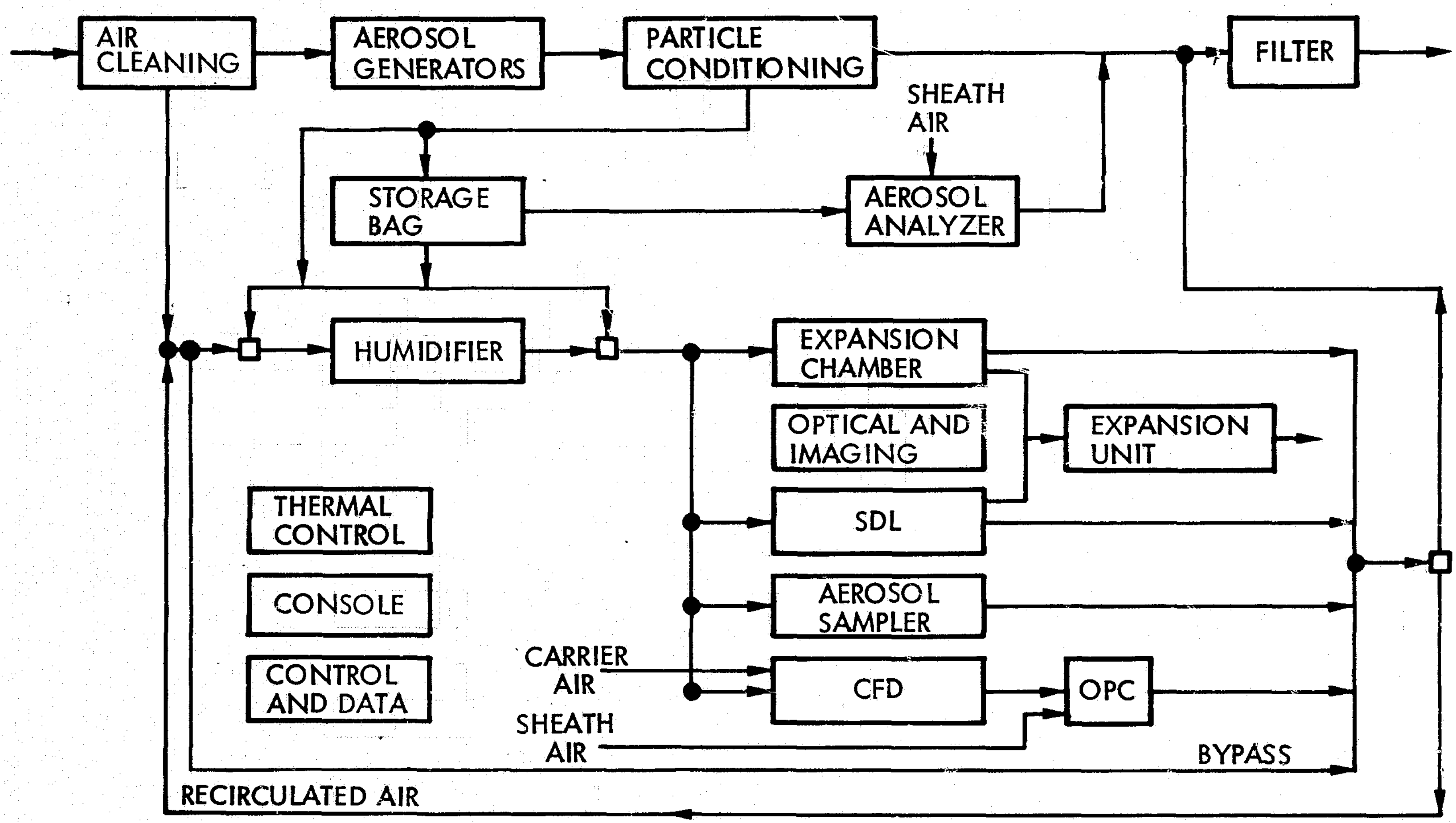
SUMMARY OF ACPL PRELIMINARY DESIGN STATUS

- SIGNIFICANT MODIFICATIONS TO GROUND-BASED CFD DESIGNS NECESSARY TO MEET REQUIREMENTS. COMPLETED PRELIMINARY DESIGN INCORPORATES NOVEL TECHNIQUE TO MINIMIZE SAMPLE ENTRANCE LOSSES, DOWNSTREAM SAMPLE INJECTION, WICKING SYSTEM FOR VERTICAL OPERATION IN 1 G, ETC.
- DETAILED ANALYSIS OF FLUID SUBSYSTEM DEMONSTRATES LOOP STABILITY, SUBSYSTEM REQUIREMENTS CAN BE SATISFIED WITH COMMERCIAL EQUIPMENT. LOOP CONFIGURATION MAXIMIZES KEY FLOWS TO MINIMIZE AEROSOL LOSSES, HAS CONSIDERABLE FLEXIBILITY TO ACCOMMODATE LABORATORY GROWTH.
- AEROSOL GENERATION TECHNIQUES SELECTED BASED ON EXISTING LABORATORY TECHNIQUES. SYSTEM INCLUDES CAPABILITY TO INCLUDE STABLE GENERATOR(S) WHEN DEVELOPED.
- PRELIMINARY DESIGN OF THE EXPANSION CHAMBER CONTINUES. DETAILED ANALYSIS HAS LED TO A MODIFICATION OF THE THERMAL CONTROL APPROACH SHOWN IN CONCEPT REVIEW. TURBULENT JETS APPEAR REQUIRED TO PROMOTE ACCEPTABLE MIXING.
- AUTORADIOGRAPHIC TECHNIQUE DEVELOPED AT MSFC MAY DRAMATICALLY REDUCE EXPANSION CHAMBER ILLUMINATION POWER REQUIREMENTS, ALLOW FOR IMPROVED PERFORMANCE OR SIMPLIFY OPTICS.
- SOFTWARE ARCHITECTURE COMPLETED. PROVIDES MAXIMUM FLEXIBILITY, COMMONALITY OF GROUND AND FLIGHT SOFTWARE ELEMENTS.

TRW
SYSTEMS GROUP

The system block diagram identifies the major functional elements of the ACPL. The interrelationship of the elements is shown from the standpoint of the fluid system. A more detailed diagram showing each component is presented in the discussion of the Fluid Subsystem.

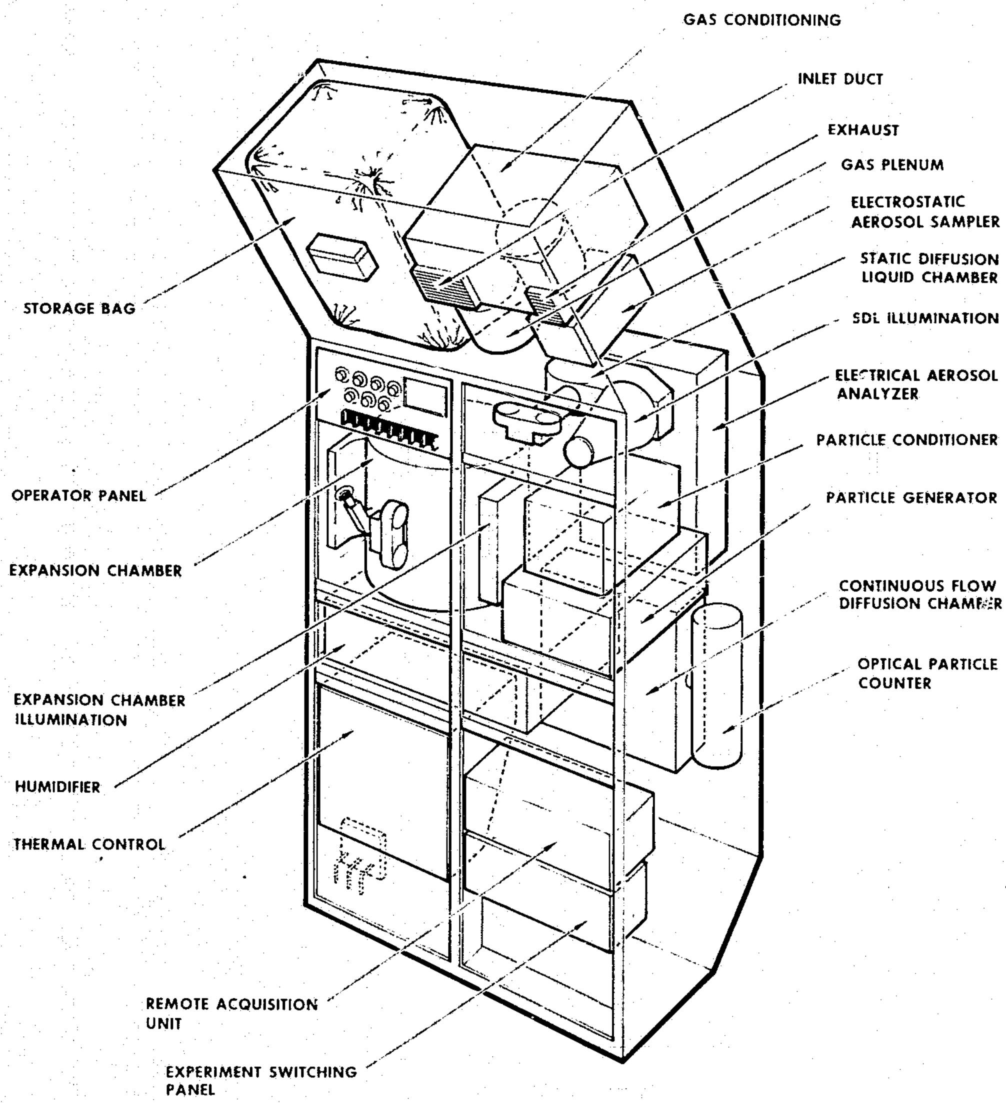
ACPL SYSTEM BLOCK DIAGRAM



TRW
SYSTEMS GROUP

The ACPL double rack packaging concept shows the relative locations selected for the major ACPL equipment items.

ACPL PACKAGING LAYOUT



PRECEDING PAGE BLANK NOT FILMED

TECHNICAL DISCUSSION AND PRELIMINARY DESIGN

LARRY HARNETT
BRUCE MARCUS
RALPH SCHILLING

TRW SYSTEMS GROUP

PRECEDING PAGE BLANK NOT FILMED

EXPERIMENTAL CHAMBER SUBSYSTEMS

TRW SYSTEMS GROUP

CONTINUOUS FLOW DIFFUSION CHAMBER SUBSYSTEM

The internal chamber configuration, sample entry subassembly, wick system and thermal control approach are the major areas considered in the design of the CFD. Each design element shall be discussed in detail. However, key features to look for include:

- o An internal configuration which provides for downstream sample injection to minimize aerosol activation errors.
- o A novel approach to controlling aerosol diffusion losses from the sample which involves bleeding clean air through a porous sample tube to keep the aerosol away from the walls.
- o A wick system which allows vertical operation in a 1-g field to yield ground based test data similar to o-g performance.
- o A pumped freon thermal control subsystem which provides maximum temperature control in the critical activation and growth region.

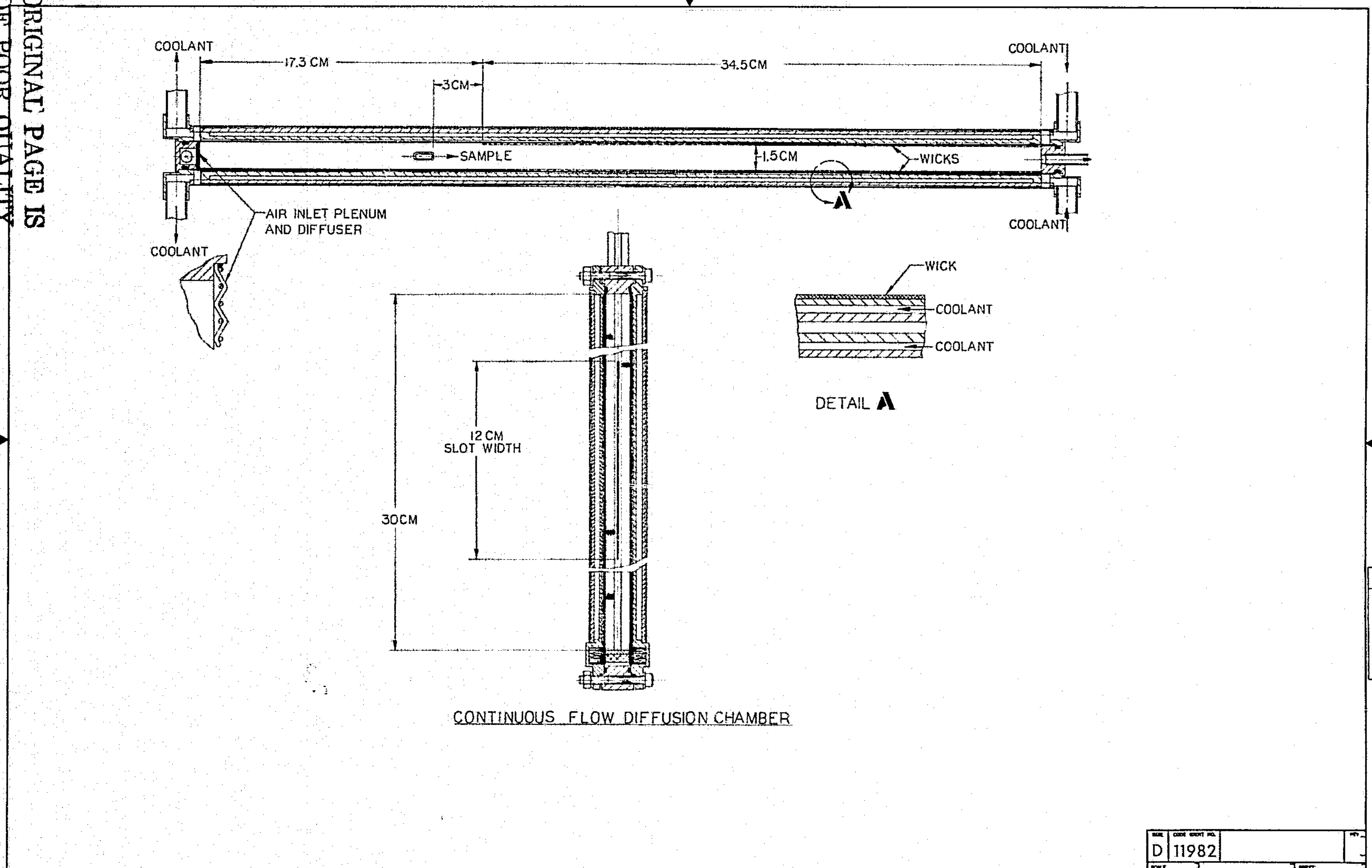
CONTINUOUS FLOW DIFFUSION CHAMBER DESIGN ELEMENTS

- INTERNAL CHAMBER CONFIGURATION
- SAMPLE ENTRY SUBASSEMBLY
- WICK SYSTEM
- THERMAL CONTROL

TRW SYSTEMS GROUP

Physically, the CFD consists of two parallel plates with wetted wicks over appropriate lengths through which an aerosol sample is transported in a carrier air stream. The plates are maintained at a controlled temperature difference leading to a known supersaturation field between them. The aerosol passing through this field activates and grows to droplets of a size observable with an Optical Particle Counter. Only those aerosol particles with critical supersaturations (S_c) less than the supersaturation field undergo the activation and growth process. Thus, by varying the supersaturation field (ΔT between the plates), the CFD serves as a spectrometer in S_c.

CFD LAYOUT


COOLANT
17.3 CM
34.5CM
3CM
COOLANT
SAMPLE
1.5CM
WICKS
COOLANT
AIR INLET PLENUM
AND DIFFUSER
COOLANT
WICK
COOLANT
COOLANT
DETAIL A
12 CM
SLOT WIDTH
30CM
CONTINUOUS FLOW DIFFUSION CHAMBER
D 11982

The Level I Specification requirements and other design objectives pertaining to the CFD internal configuration are shown on the facing page.

The driving requirement is to activate, grow and count 99 percent of the aerosol with critical supersaturation below the theoretical chamber maximum.

INTERNAL CHAMBER CONFIGURATION

REQUIREMENTS AND OBJECTIVES:

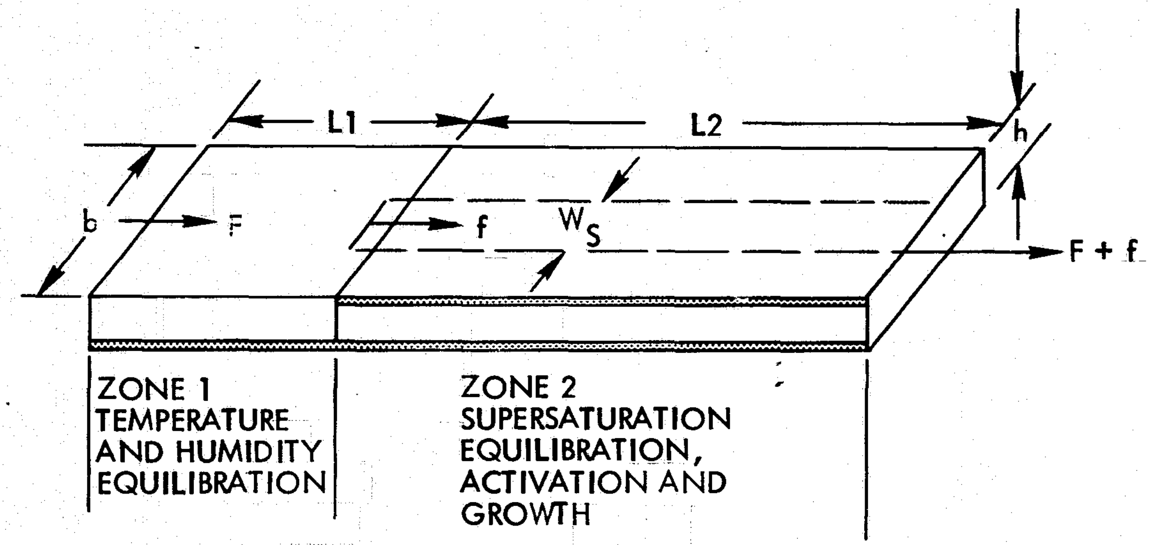
- 99 PERCENT OF AEROSOL WITH $S_C < S_M$ SHALL BE ACTIVATED, GROWN AND COUNTED FOR $0.1 \leq S_M \leq 1.0\%$
- OPERATING RANGE IN S_M: $0.05 \leq S_M \leq 3.0\%$
  PRIMARY RANGE IN S_M: $0.1 \leq S_M \leq 1.0\%$
- OPERATING TEMPERATURE RANGE: $0.5 \leq T_M \leq 25°C$
- WIDTH OF CHAMBER: $b \geq 12h + W_S$
- AEROSOL DENSITY: $100 \leq No \leq 2000$ PARTICLES/CM^3 WITH $0.1 \leq S_C \leq 1\%$
- MINIMUM RESIDENCE TIMES: ZONE 1, $t_1 \geq 5\tau_W$, $t_1 \geq 5\tau_H$
  ZONE 2, $t_2 \geq 7\,\tau_W + t_g$
- DESIGN MUST ALLOW FOR HIGH ENOUGH SAMPLE FLOW RATES TO YIELD REASONABLE COUNTING TIMES AND PERMIT ACCURATE MEASUREMENT
- DESIGN AND OPERATION MUST AVOID TRANSIENT SUPERSATURATIONS IN EXCESS OF S_M

TRW
SYSTEMS GROUP

The CFD is divided into two zones. In zone 1, only the cold plate is wet and the carrier flow (F) comes to temperature and humidity equilibration. The Sample (f) is introduced near the start of zone 2, where both plates are wet. In this zone the humidity level equilibrates at the supersaturation condition, the aerosol sample is activated, and the activated particles grow to a sufficient size to be detected with the Optical Particle Counter.

The sample is introduced near the start of zone 2 rather than at the beginning of the chamber to minimize the displacement of the sample lamina boundary and assure 99% activation. This will be discussed further on the following pages.

INTERNAL CHAMBER CONFIGURATION



- TWO PARALLEL PLATES WITH CONTROLLED ΔT
- ZONE 1: COLD PLATE WET – TEMPERATURE AND HUMIDITY EQUILIBRATION OF CARRIER FLOW
- ZONE 2: BOTH PLATES WET – DEVELOPMENT OF SUPERSATURATION FIELD, ACTIVATION OF AEROSOL WITH $S_C \leq S_M$, DROPLET GROWTH
- SAMPLE ENTRY NEAR START OF ZONE 2 TO MINIMIZE DISPLACEMENT AND SPREADING OF SAMPLE LAMINA

TRW
SYSTEMS GROUP

To assure activation of $>99\%$ of the aerosol, the combined effects of diffusion, conservation of mass and phoresis must not be permitted to displace the sample lamina boundary beyond tolerable limits.

Because the displacement phenomena are time dependent, their effect is minimized by injecting the aerosol at the start of zone 2 rather than the start of the chamber as is conventional practice.

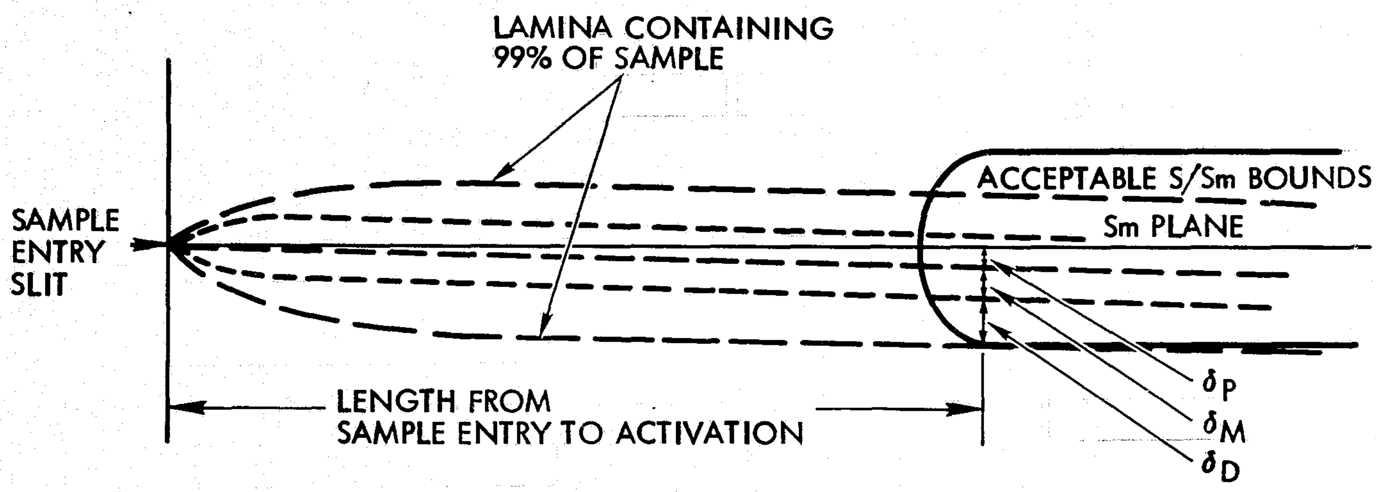
AEROSOL ACTIVATION: SAMPLE BOUNDARY DISPLACEMENT

- MUST ACTIVATE >99% OF AEROSOL WITH $S_C \leq S_M$
- APPROXIMATELY PARABOLIC DISTRIBUTION IN S BETWEEN PLATES
- MUST CONSTRAIN SAMPLE TO THIN LAMINA ABOUT S_M PLANE
- SAMPLE MOVEMENT:

  δ_D – SAMPLE SPREADING DUE TO DIFFUSION

  δ_M – SAMPLE SPREADING DUE TO CONSERVATION OF MASS AS SAMPLE AND CARRIER VELOCITIES EQUALIZE

  δ_P – SAMPLE DISPLACEMENT BY DIFFUSIO- AND THERMOPHORESIS



- δ_D AND δ_P ARE TIME DEPENDENT. EFFECTS ARE MINIMIZED WITH DOWNSTREAM INJECTION
- DOWNSTREAM INJECTION ALSO ELIMINATES NEED FOR A PRELIMINARY ZONE WITH BOTH PLATES DRY. TRANSIENT SUPERSATURATIONS DO NOT AFFECT SAMPLE

TRW SYSTEMS GROUP

The relevant equations for establishing the activation conditions are shown on the facing page. These equations must be satisfied at the worst case primary design conditions.

Two key assumptions have been made which lead to a conservative design. One is that the activation time for the aerosol corresponds to the seven time constants needed to develop the supersaturation profile. The second is that the aerosol diffusivity has been based on the dry crystal size, neglecting the beneficial effects of deliquescence.

A key observation is that all terms in the activation criterion are functions of the plate spacing. By evaluating them parametrically in h, we can determine whether there exists an optimum plate spacing.

AEROSOL ACTIVATION

- WORST CASE PRIMARY DESIGN CONDITIONS:

  $T_M = 0.5°C,\ N = CS^{1.0},\ S_M = 1.0\%$

- ASSUME ALL PARTICLES WITH $S_C < S_M$ ACTIVATE BY THE TIME $S = S_M$

- $\delta_D = \beta\sqrt{4Dt} = 0.0505h$ (99% OF PARTICLES, NEGLECTS DELIQUESENCE)

  $$\delta_M = \frac{fbh}{3(F+f)W_S} = \frac{h(1.5h+1)}{3}\cdot\left(\frac{f}{f+F}\right) \qquad (b = 12h + W_S;\ W_S = 8\ \text{CM})$$

  $$\delta_P = 2.9 \times 10^{-3} \div \sqrt{S_M} = 0.0096h^2$$

- SUPERSATURATION PROFILE: $Z = \frac{h}{2}\left(1 - \frac{S}{S_M}\right)^{1/2}$

- ACTIVATION ERROR DUE TO SAMPLE THICKNESS AND DISPLACEMENT:

  $$\frac{\delta N}{N} \approx \frac{\left(1 - \frac{S}{S_M}\right)k}{3}\ ; \text{ FOR 1\% ERROR } S/S_M \geq 0.97,\ k = 1.0$$
  $$S/S_M \geq 0.94,\ k = 0.5$$

- FOR 99% ACTIVATION:

  $$\delta_P + \delta_M + \delta_D \leq \frac{h}{2}\left(1 - \frac{S}{S_M}\right)^{1/2};\ S/S_M = 0.97,\ k = 1.0$$
  $$S/S_M = 0.94,\ k = 0.5$$

- ALL TERMS ARE FUNCTION OF PLATE SPACING

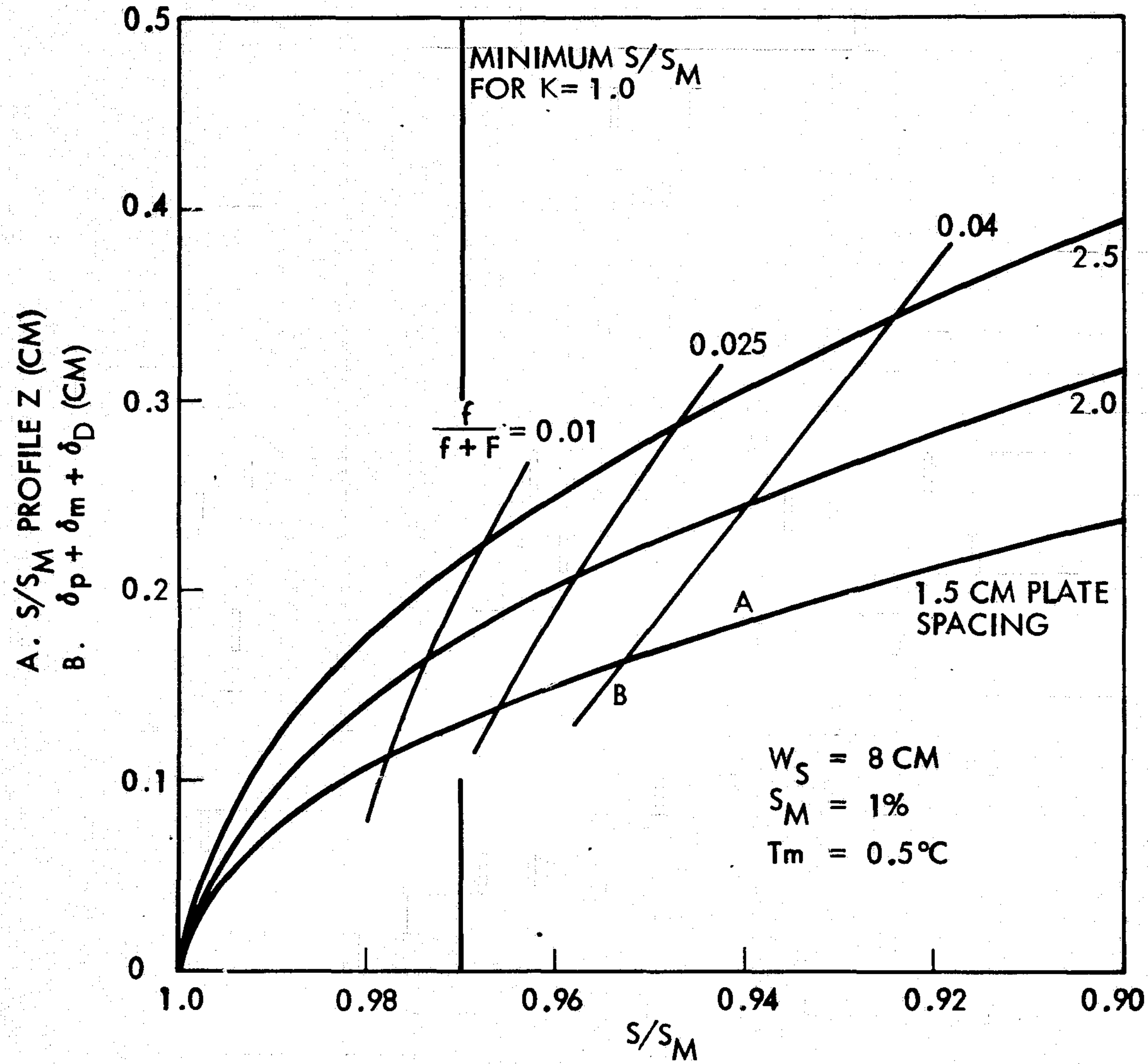
TRW SYSTEMS GROUP

Two series of curves are shown on the facing graph. One is the supersaturation profile between plates with spacing as a parameter. The second shows the sample boundary displacement for each plate spacing with sample to total flow ratio as a parameter.

A key results is that there exists no optimum plate spacing. Smaller spacing results in sample activation within higher supersaturation profiles, yielding smaller activation errors. A 1.5 cm spacing has been selected to allow room for the sample entry tube to pass between the plates without excessive disturbance of the carrier flow field.

A second key results is that the activation criterion sets an upper limit on the ratio of the flow from the sample slit to the total flow. This limit can be increased by increasing the length of the sample slit.

AEROSOL ACTIVATION: EFFECT OF PLATE SPACING



- NO OPTIMUM IN SPACING
- SELECT h = 1.5 CM TO ALLOW ROOM FOR SAMPLE TUBE
- $f / f + F \leq 0.02$ TO REMAIN WITHIN ACCEPTABLE S/S_M PROFILE FOR k = 1 AND W_S = 8 CM

TRW SYSTEMS GROUP

Sample activation errors also arise from phenomena which affect the axial development of the supersaturation profile along the S_M plane.

Longitudinal diffusion of water vapor from zone 2 to zone 1 slows the development of the supersaturation profile, increasing the sample residence time required for activation and, therefore, the lateral displacement of the sample boundary. This effect becomes intolerable for centerline carrier flow velocities less than about 0.5 cm/sec.

It will be seen later that we want to minimize the lower bound on carrier flow rate to minimize the required chamber length. Thus, if we set the lower bound equal to the OPC limit, the minimum velocity constraint establishes a maximum chamber width of 30 cm for a 1.5 cm plate spacing. This in turn establishes a maximum sample slit length of 12 cm to avoid side wall effects.

AEROSOL ACTIVATION: APPROACH TO THEORETICAL S_M

- LONGITUDINAL DIFFUSION OF WATER VAPOR SLOWS DEVELOPMENT OF SUPERSATURATION PROFILE

- REQUIRE MINIMUM CENTERLINE CARRIER VELOCITY OF ~ 0.5 CM/SEC

$$U_{MIN} = 3F/2bh \geq 0.5 \text{ CM/SEC}$$

- WANT TO MINIMIZE LOWER BOUND ON CARRIER FLOW TO MINIMIZE CFD LENGTH. LOWER BOUND FOR OPC IS $F = 15$ CM^3/SEC

- FOR PLATE SPACING OF 1.5 CM AND $F_{MIN} = 15$ CM^3/SEC:

  MAXIMUM CHAMBER WIDTH = 30 CM

  MAXIMUM SAMPLE SLIT LENGTH = 12 CM

TRW
SYSTEMS GROUP

A second phenomenon which alters the axial development of the supersaturation profile is vapor depletion by the growing droplets. This results in an actual maximum supersaturation - S_M^1 lower than the theoretical value based on plate temperatures - S_M. To constrain the activation error to 1% for an aerosol with k = 1, it is necessary that $S_M^1 / S_M \geq 0.99$.

This depletion effect gives rise to a maximum permissible droplet flow rate.

The maximum droplet flow rate and the aerosol distribution lead to an upper limit on the sample-to-carrier flow rate ratio.

Note that depletion limits the actual sample flow - f_s whereas sample spreading by conservation of mass limits the flow out of the sample slit-f. These flows differ slightly because the sample is diluted with a clean air flow in order to control diffusion losses.

AEROSOL ACTIVATION: APPROACH TO THEORETICAL S_M

- VAPOR DEPLETION BY GROWING DROPLETS YIELDS MAXIMUM SUPERSATURATION (S'_M) LOWER THAN THEORETICAL VALUE (S_M) BASED ON PLATE TEMPERATURES

- ACTIVATION ERROR DUE TO DEPLETION

$$\frac{\delta N}{N} = 1 - \left(\frac{S'_M}{S_M}\right)^k; \text{ FOR 1\% ERROR } \quad \frac{S'_M}{S_M} \geq 0.99,\ k = 1.0$$

$$\frac{S'_M}{S_M} \geq 0.98,\ k = 0.5$$

- MAXIMUM DROPLET FLOW RATE

$$D_{MAX} = 6000F\ W_S \left(1 - \frac{S'_M}{S_M}\right) / bh^2$$

- MAXIMUM SAMPLE FLOW RATE

$$\frac{f_s}{F} \leq \frac{D_{MAX}}{FN};\ N = C\ S'^{\,k}_M$$

- SAMPLE FLOW fs $\leq$ SLIT FLOW f DUE TO SAMPLE DILUTION

TRW SYSTEMS GROUP

To achieve a high level of accuracy in the CFD it is not sufficient to assure that nearly all the aerosol with $S_C \leq S_M$ be activated, but it is also necessary to assure that the activated nuclei grow to sufficient size to enable them to be 1) counted in the OPC, and 2) distinguished from inactivated haze droplets. Empirical data provided by Desert Research Institute indicate that droplet growth will be assured if the sample spends the minimum growth time shown within the $S/S_M = 0.90$ profile beyond the activation zone.

Thus, our design criteria is to constrain the sample to the 0.97 S/S_M profile for activation, but only to the 0.90 S/S_M profile for droplet growth.

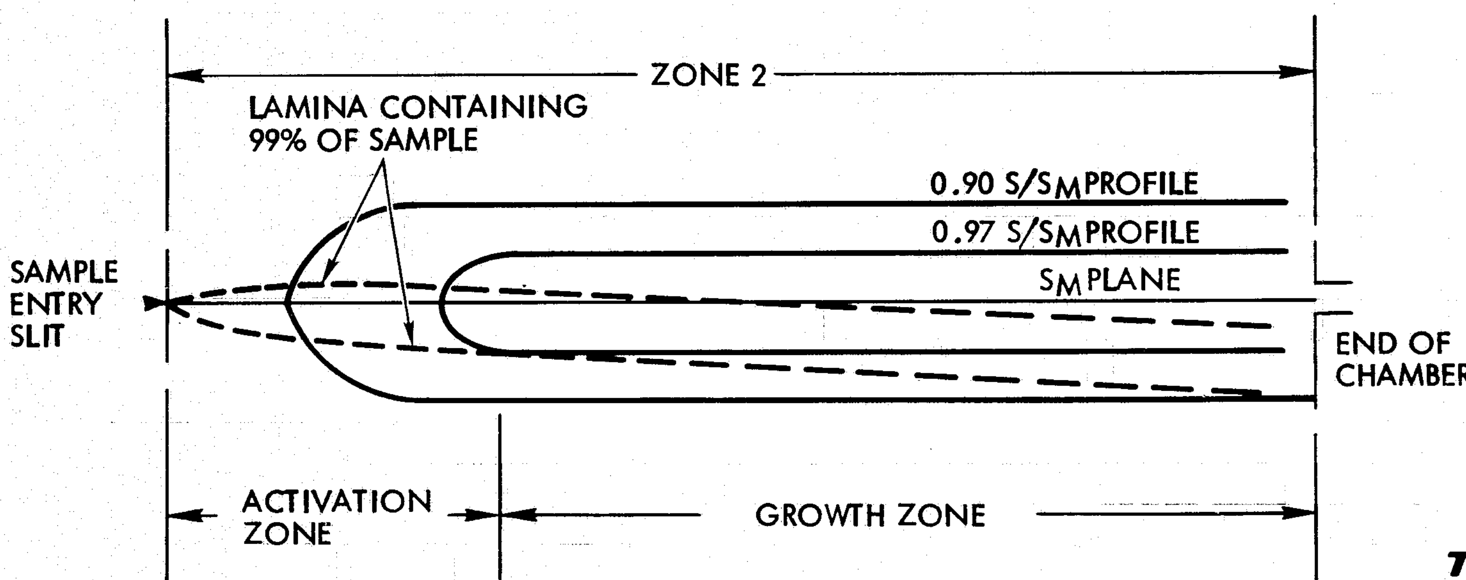
DROPLET GROWTH

- MUST ASSURE ACTIVATED AEROSOL GROWS TO SUFFICIENT SIZE TO BE COUNTED IN OPC AND DISTINGUISHED FROM HAZE DROPLETS

- REQUIRED GROWTH TIME WITHIN 0.90 S/S_M PROFILE:

S_M (%)	t_g (SEC)
0.1	50
0.35	25
1.0	5

- MUST CONSTRAIN SAMPLE TO 0.90 S/S_M PROFILE IN GROWTH REGION



TRW SYSTEMS GROUP

CRITERIA FOR MAXIMUM SAMPLE BOUNDARY DISPLACEMENT DURING ACTIVATION AND DROPLET GROWTH

The internal chamber configuration and carrier flow rates must be selected to accommodate several limitations on residence time in zones 1 and 2. These limits are set to assure sufficient time for temperature and humidity equilibration in zone 1, and activation and growth of the aerosol in zone 2; and to limit the phoretic displacement of the sample lamina boundary to the .90 S/S_M profile.

Upper and lower bounds on the total residence time in the chamber are related to the limits in zones 1 and 2 by the appropriate length ratios.

Since the carrier flow rate and chamber residence time are related through the chamber dimensions, limits on the chamber residence time correspond to limits on the carrier flow rate.

INTERNAL CHAMBER CONFIGURATION: LIMITS ON RESIDENCE TIME

- INTERNAL CONFIGURATION AND CARRIER FLOW RATES MUST PROVIDE FOR:

  A) RESIDENCE TIME IN ZONE 1 $\geq t_1 = 5\tau_H$ OR $t_1' = 5\tau_W$ FOR ALL F

  B) RESIDENCE TIME IN ZONE 2 $\geq t_2(S_M) = 7\tau_W + t_g(S_M)$ FOR ALL F, S_M

  C) RESIDENCE TIME IN ZONE 2 $\leq t_p(S_M) = \delta_p / V_p(S_M)$ FOR ALL F, S_M

  $\delta_p = 0.236 - \delta_M - \delta_D$ FOR 0.90 S/S_M PROFILE, $h = 1.5$ CM

- CORRESPONDING LIMITS ON CHAMBER RESIDENCE TIME ARE:

  A) $t_r \geq t_1(L_1 + L_2)/L_1$

  B) $t_r \geq t_2(S_M)(L_1 + L_2)/L_2$

  C) $t_r \leq t_p(S_M)(L_1 + L_2)/L_2$

- CARRIER FLOW RATE IS RELATED TO CHAMBER RESIDENCE TIME:

  $F = 2\,bh(L_1 + L_2)/3\,t_r$

TRW
SYSTEMS GROUP

An analysis of actual residence time in the chamber shows that the minimum length CFD which satisfies all of the limits on residence time within the primary operating range must have the zone lengths shown on the facing page.

Values for θ (≥ 1) and $\emptyset$ (≤ 1) are selected to provide a range in carrier flow rate which satisfies all criteria at the lower and upper ends of the primary operating range, respectively. This assures the existence of operating plateaus in F which simplifies the problem of flow control by the Fluid Subsystem.

The appropriate value for the minimum carrier flow is the OPC limit (15 cm^3/sec) since the chamber height and width have been selected such that this provides a minimum centerline velocity of 0.5 cm/sec.

INTERNAL CHAMBER CONFIGURATION: ZONE LENGTHS

- ALL RESIDENCE TIME CRITERIA ARE SATISFIED IN PRIMARY OPERATING RANGE $(0.1 \leq S_M \leq 1.0\%)$ WITH:

ZONE 1: $$L_1 = \frac{3\,F_{MIN}\,\Theta\,t_2(0.1\%)\,t_1}{2\,bh\,\phi\,t_p(1\%)}$$

ZONE 2: $$L_2 = \frac{3\,F_{MIN}\,\Theta\,t_2(0.1\%)}{2\,bh}$$

$\Theta \geq 1$, $\phi \leq 1$ SELECTED FOR DESIRED OPERATING PLATEAUS IN F

TRW SYSTEMS GROUP

On the supposition that a minimum acceptable range in allowable carrier flow rate is $\pm$ 10% at all values of S_M in the primary range ($0.1 \leq S_M$ 1.0%), we set $\theta = 1.2$ and $\emptyset = 0.8$. This results in a design for the minimum length CFD as shown.

Note that the required length of zone 1 is only 6.0 cm and the total chamber length is 40.5 cm.

INTERNAL CHAMBER CONFIGURATION: MINIMUM LENGTH CFD

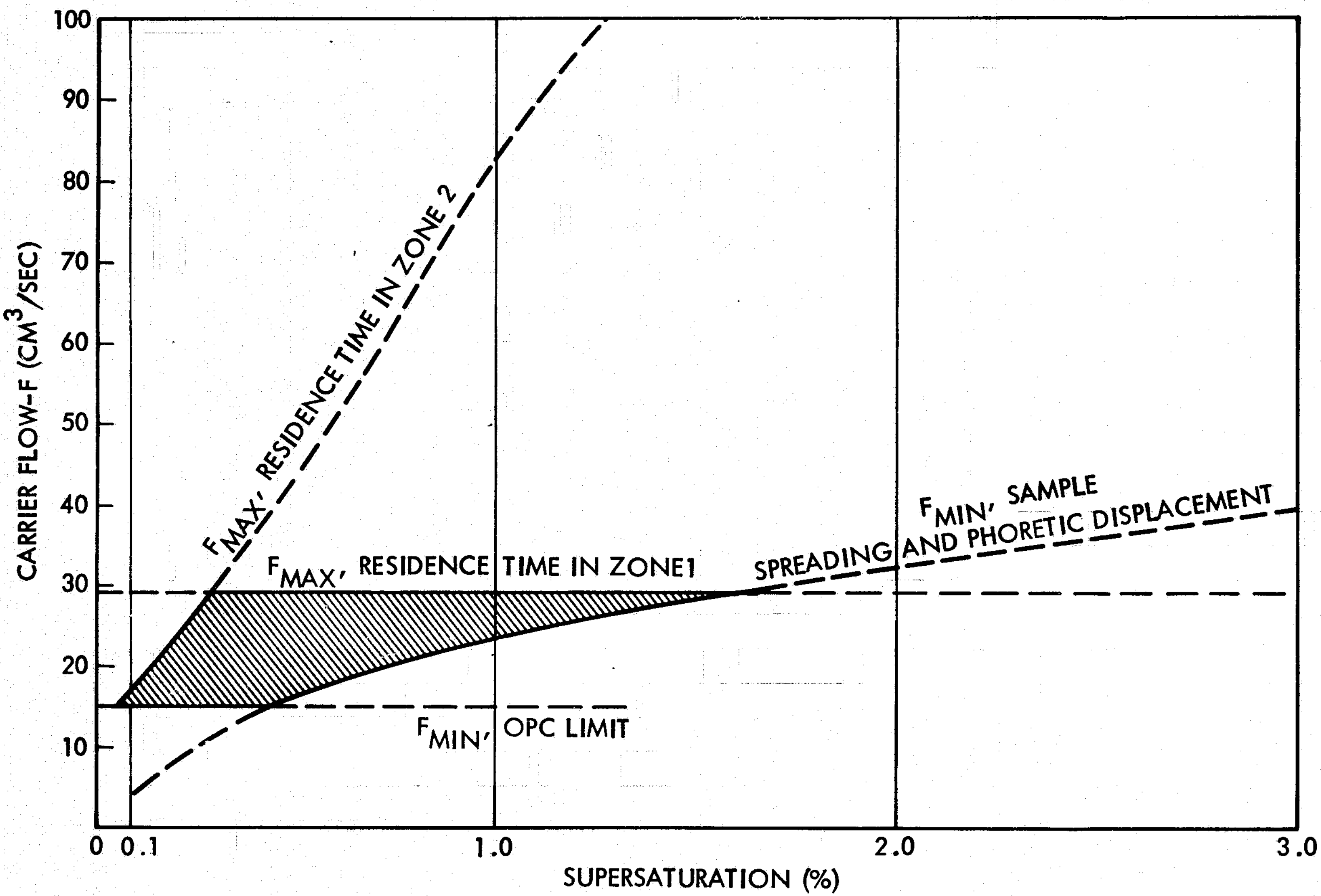
DESIGN CONDITIONS	
MEAN PLATE TEMPERATURE	0.5°C
AEROSOL DISTRIBUTION	$N = 2000S^{1.0}$, $N \le 2000$ PART/CM^3
PLATE SPACING - h	1.5 CM
CHAMBER WIDTH - b	30 CM
SAMPLE WIDTH - W_S	12 CM
PLATEAUS IN F $\ge 20\%$	$\Theta = 1.2$, $\emptyset = 0.8$
MINIMUM CARRIER FLOW	15 CM^3/SEC (OPC LIMIT)
TRANSVERSE ACTIVATION PROFILE	$S/S_M \ge 0.97$
TRANSVERSE GROWTH PROFILE	$S/S_M \ge 0.90$
ANALYSIS RESULTS	
CHAMBER LENGTH	40.5 CM
ZONE 1	6.0 CM
ZONE 2	34.5 CM
CARRIER FLOW RATE	15 - 29 CM^3/SEC
MINIMUM CENTERLINE VELOCITY	0.5 CM^3/SEC

TRW
SYSTEMS GROUP

The figure on the facing page shows the operating range in carrier flow rate which meets the activation and growth criteria, and the phenomena which limit it. Within the range $0.1 \leq S_M \leq 1.0\%$, there exists a minimum range in F of 20%, as specified.

Note that this CFD would operate outside of the shaded area (e.g., up to $S_M = 3\%$), but that the design critiera for activating and growing 99% of the aerosol will not be met.

CARRIER FLOW RATE OPERATING ENVELOPE
MINIMUM LENGTH CFD



TRW
SYSTEMS GROUP

The results for maximum droplet flux and maximum sample flow rate for the minimum length CFD are based on the maximum carrier flow rates from the preceding figure and an assumed (worst case) aerosol distribution of $N = 2000\ S^{1.0}$.

The depletion limit on the sample flow rate ($f_s \leq 0.155\ cm^3/sec$) is too low. Such a low flow rate is difficult to measure with 1% accuracy, aerosol diffusion losses in the sample entry subassembly would be too high, and the counting times needed for statistical accuracy would be too long.

This situation can be improved by increasing the upper bound on the maximum carrier flow rate through an increase in the length of zone 1.

INTERNAL CHAMBER CONFIGURATION: MINIMUM LENGTH CFD

ANALYSIS RESULTS

MAXIMUM DROPLET FLOW	$S_M = 0.1\%$	$D_{MAX} = 192$ (DROPS/SEC)
$(S'_M/S_M \geq 0.99)$	$S_M = 0.5\%$	$D_{MAX} = 310$ (DROPS/SEC)
	$S_M = 1.0\%$	$D_{MAX} = 310$ (DROPS/SEC)

MAXIMUM SAMPLE FLOW

- SAMPLE SPREADING LIMIT $f/F \leq 0.025$, $f \leq 0.727\ CM^3/SEC$ AT $S_M = 1\%$
- DEPLETION LIMIT $f_s/F \leq 0.0053$, $f_s \leq 0.155\ CM^3/SEC$ AT $S_M = 1\%$

- LIMIT ON f_s IS TOO LOW
- INCREASE F_{MAX} BY INCREASING LENGTH OF ZONE 1

TRW
SYSTEMS GROUP

Increasing the length of zone 1 from 6.0 to 17.3 cm yields our recommended internal chamber configuration. Zone 2 remains unchanged so that the total chamber length is now 51.8 cm.

This change increases the maximum allowable carrier flow rate over most of the operating range and, consequently, the maximum droplet flow as limited by vapor depletion.

INTERNAL CHAMBER CONFIGURATION: RECOMMENDED DESIGN

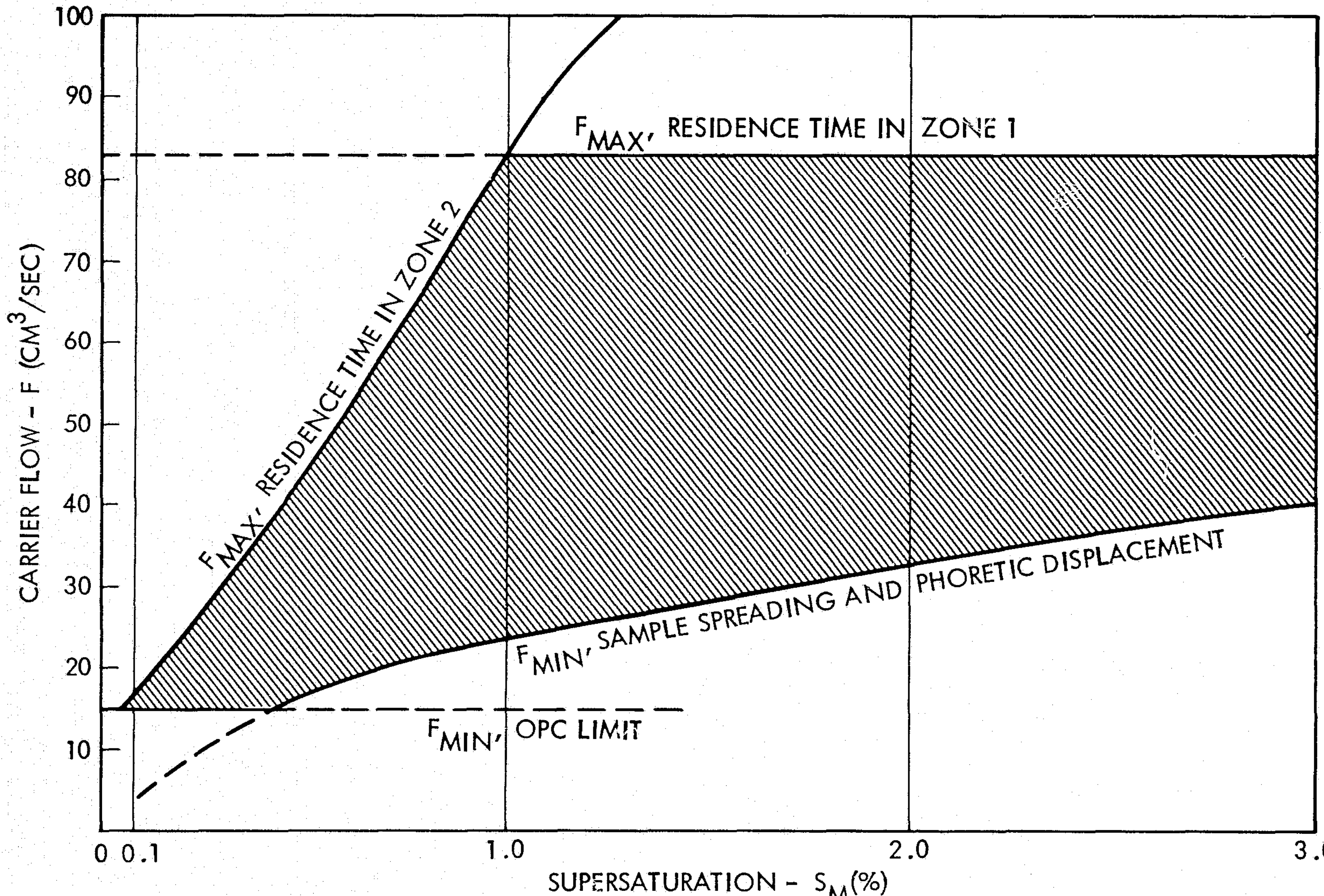
DESIGN CONDITIONS:	
MEAN PLATE TEMPERATURE	0.5°C
AEROSOL DISTRIBUTION	$N = 2000S^{1.0}$, $N \leq 2000$ PART/CM^3
PLATE SPACING	1.5 CM
CHAMBER WIDTH	30 CM
SAMPLE WIDTH	12 CM
PLATEAUS IN F ≥20%	$\Theta = 1.2$, $\emptyset = 0.28$
MINIMUM CARRIER FLOW	15 CM^3/SEC
TRANSVERSE ACTIVATION PROFILE	$S/S_M \geq 0.97$
TRANSVERSE GROWTH PROFILE	$S/S_M \geq 0.90$
ANALYSIS RESULTS	
CHAMBER LENGTH	51.8 CM
ZONE 1	17.3 CM
ZONE 2	34.5 CM
CARRIER FLOW RATE	15 - 83 CM^3/SEC
MINIMUM CENTERLINE VELOCITY	0.5 CM/SEC
MAXIMUM DROPLET FLOW ($S_M/S_M \geq 0.99$)	$S_M = 0.1\%$ $D_{MAX} = 192$ (DROPS/SEC)
	$S_M = 0.5\%$ $D_{MAX} = 470$ (DROPS/SEC)
	$S_M \geq 1.0\%$ $D_{MAX} = 885$ (DROPS/SEC)

TRW SYSTEMS GROUP

Our recommended design provides a much greater range in permissible carrier flow rates than the minimum length CFD. The activation and growth requirements can now be satisfied over the entire operating range in supersaturation ($0.05 \leq S_M \leq 3.0\%$).

A major advantage of this operating flexibility is that only two discrete carrier flow settings are needed for the primary operating range in S_M, and three for the total operating range. When compared with continuously varying the carrier flow rate with supersaturation, this significantly simplifies the requirements on the Fluid Subsystem.

CARRIER FLOW RATE OPERATING ENVELOPE
RECOMMENDED DESIGN



- ACTIVATION AND GROWTH REQUIREMENTS SATISFIED OVER ENTIRE OPERATING RANGE IN S_M

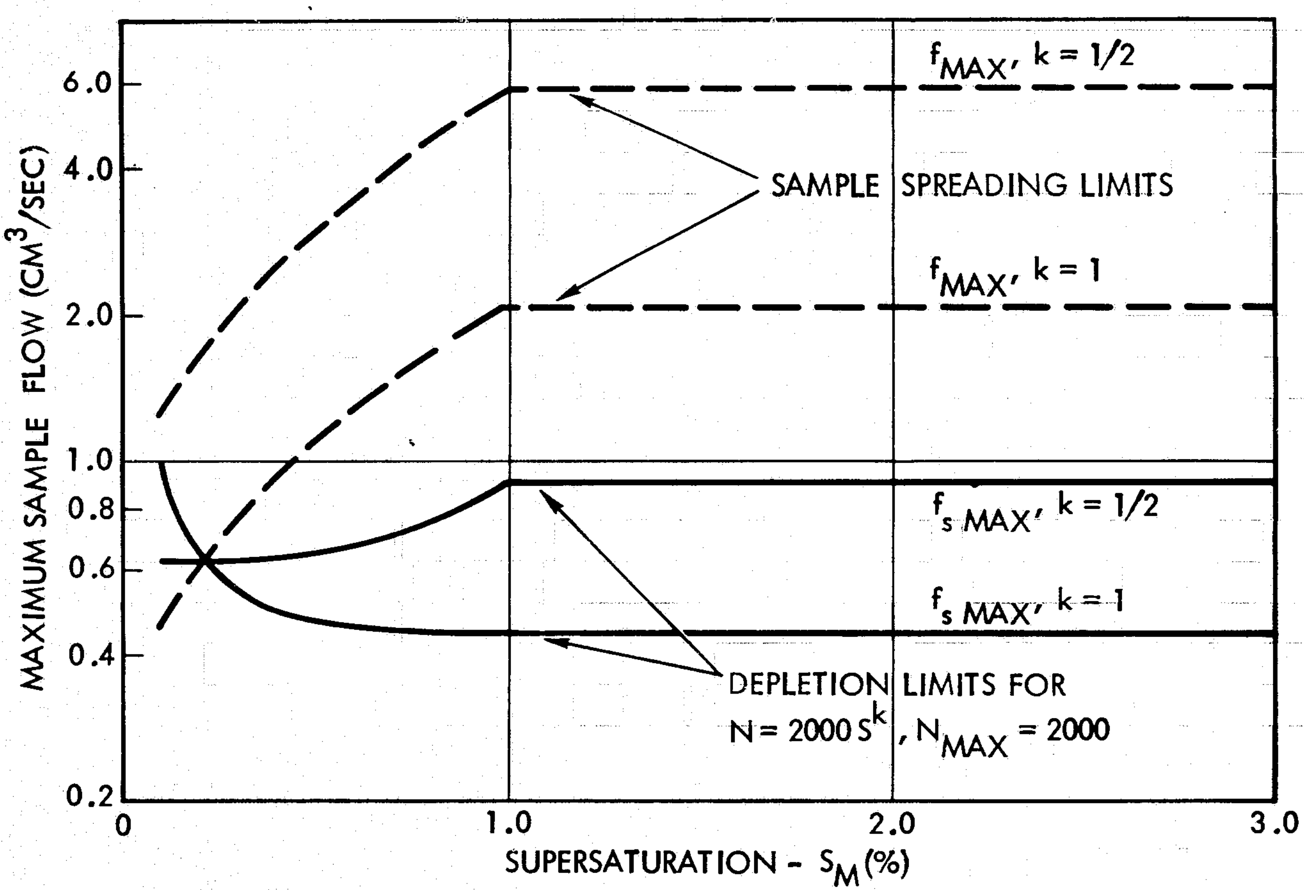
TRW
SYSTEMS GROUP

The maximum sample flow, as limited by depletion and sample spreading, is shown on the facing page.

The depletion effect limits the actual aerosol sample flow - f_s whereas sample spreading limits the flow from the sample entry slit -f. The flow through the slit will be larger than the sample flow due to some clean air dilution needed to control aerosol diffusion losses.

The results of our conservative analysis indicate that a constant sample flow of 0.4 cm^3/sec will be satisfactory under all required operating conditions. However, higher sample flows, when permitted by the aerosol distribution, will shorten the counting time required for statistical accuracy.

MAXIMUM SAMPLE FLOW – RECOMMENDED DESIGN



- CONSTANT SAMPLE FLOW OF 0.4 CM^3/SEC WILL SATISFY REQUIREMENTS UNDER ALL CONDITIONS
- HIGHER SAMPLE FLOW WHEN PERMITTED BY AEROSOL DISTRIBUTION WILL SHORTEN COUNTING TIME REQUIRED FOR STATISTICAL ACCURACY

TRW SYSTEMS GROUP

The requirements and objectives considered in deisgning the sample entry subassembly are listed on the facing page.

SAMPLE ENTRY SUBASSEMBLY

REQUIREMENTS AND OBJECTIVES:

- MEASURE SAMPLE FLOW RATE (~0.4 CM^3/SEC) TO 1% ACCURACY
- INTRODUCE SAMPLE UNIFORMLY ALONG SLIT WIDTH (12 CM)
- ASSURE SAMPLE VELOCITY PERTURBATION DECAYS PRIOR TO ACTIVATION ZONE
- CONTROL AEROSOL DIFFUSION LOSSES IN SAMPLE FLOW LINES AND THROUGH SLIT ($\leq$1%)

TRW
SYSTEMS GROUP

The recommended concept for providing accurate sample flow and control of the aerosol diffusion loss in the flow lines is as shown.

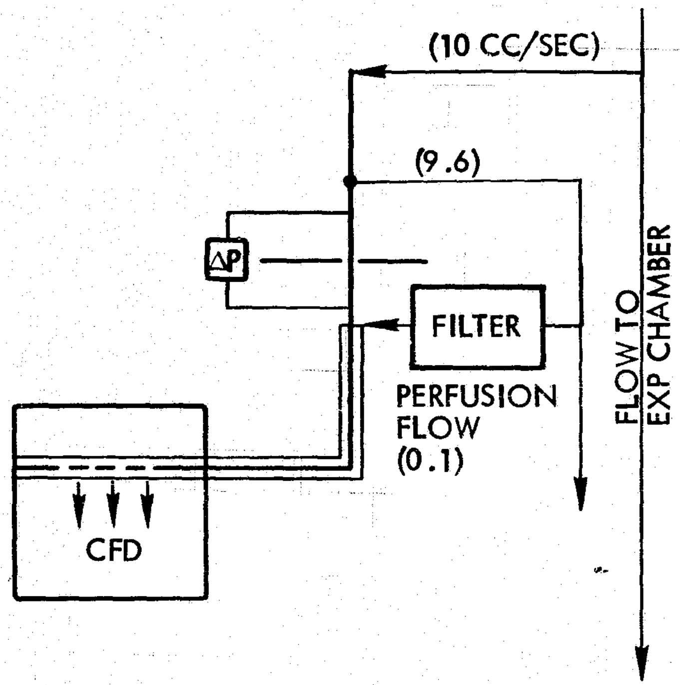
Aerosol diffusion losses are minimized when the ratio of the flow length to the flow rate is small. Thus, a large aerosol flow is drawn from the main line to the CFD.

This flow is then split and the actual sample flow measured by measuring the pressure drop across a calibrated orifice.

The excess aerosol flow is again split and a small portion filtered and returned to the sample stream as a perfusing flow through a porous sample tube to prevent the aerosol from diffusing to the walls. Only a very small perfusion flow is required.

The flow path over which the small sample flow is unprotected, i.e., from the first flow splitter to the point where the perfusing flow is added must be kept very short (<0.9 cm for a 0.4 cm^3/sec flow) to control the diffusion losses during the flow measurement step.

SAMPLE ENTRY SUBASSEMBLY
RECOMMENDED CONCEPT: FLOW SYSTEM



- DRAW LARGE FLOW FROM MAIN LINE TO MINIMIZE AEROSOL LOSS (~10 CC/SEC)
- SPLIT FLOW AND MEASURE SAMPLE FLOW (0.4 CM^3/SEC) OVER VERY SHORT LENGTH (<0.9 CM)
- SPLIT EXCESS AND RETURN A FILTERED PORTION (0.1 CM^3/SEC) AS A PERFUSING FLOW THROUGH A POROUS SAMPLE TUBE TO PREVENT DIFFUSION LOSSES TO WALLS

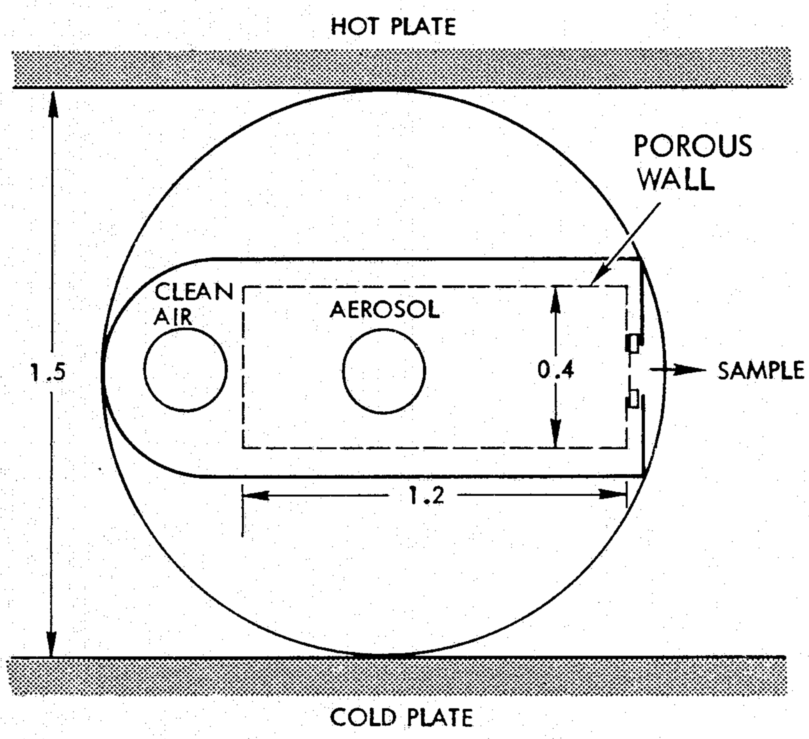
- PROVIDES ACCURATE FLOW MEASUREMENT AND CONTROL OF AEROSOL DIFFUSION LOSSES IN FLOW LINES

A sample entry channel is selected instead of a tube to increase the sample flow area without excessive carrier flow blockage. This minimizes the transverse pressure drop along the sample entry slit and promotes uniform sample injection.

The external geometry of the assembly is such as to permit slight rotation of the sample slit if necessary to accommodate the variation in position of the S_M plane with supersaturation.

The sample slit itself is fabricated from very thin foil to minimize the aerosol diffusion loss in passing through it.

SAMPLE ENTRY SUBASSEMBLY
RECOMMENDED DESIGN: SAMPLE ENTRY CHANNEL



- SAMPLE ENTRY CHANNEL INSTEAD OF TUBE INCREASES SAMPLE FLOW AREA WITHOUT EXCESSIVE FLOW BLOCKAGE
- PERFUSIVE FLOW ALONG CHANNEL PREVENTS AEROSOL LOSS IN SPITE OF SECONDARY FLOW FIELD RESULTING FROM CHANNEL
- INTERNAL FLOW DIMENSIONS

  0.4 X 1.2 CM
- EXTERNAL ASSEMBLY DIMENSIONS FIT WITHIN 1.5 CM DIAMETER PERMITTING ROTATION AND EASY ASSEMBLY.

- MINIMIZES TRANSVERSE PRESSURE DROP ALONG SAMPLE ENTRY SLIT. PROMOTES SAMPLE UNIFORMITY ALONG SLIT.

TRW
SYSTEMS GROUP

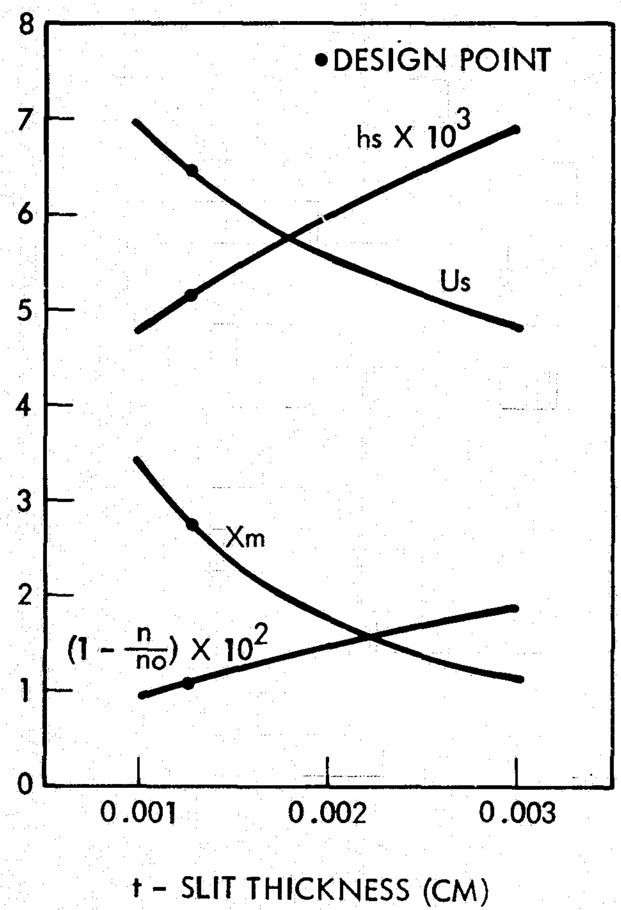
The thickness of the foil containing the sample slit will be 0.00127 cm, the thinnest material with which we have had successful fabrication experience.

This yields a maximum slit height of 0.0052 cm to assure uniform distribution of the sample.

The resulting sample exit velocity for a 0.4 cm^3/sec sample flow will be 6.46 cm/sec. By locating the slit 3 cm upstream of zone 2, this velocity will equilibrate with the carrier flow sufficiently to assure aerosol activation according to the assumed model.

The aerosol loss in passing through the slit, neglecting any beneficial effects of a clean air boundary layer due to the perfusion flow, will be less than 1.1%.

DESIGN OF SAMPLE ENTRY SUBASSEMBLY
RECOMMENDED DESIGN: SAMPLE ENTRY SLIT



	DESIGN POINT
hs - MAXIMUM SLIT HEIGHT	– 0.0052 CM
$(1 - \frac{n}{no})$ - AEROSOL DIFFUSION LOSS	– $\leq 1.1\%$
Us - SAMPLE EXIT VELOCITY	– 6.46 CM/SEC
Xm - AXIAL DISTANCE TO VELOCITY EQUILIBRATION	– 2.73 CM
t - SLIT THICKNESS	– 0.00127 CM

- LOCATE SLIT 3 CM UPSTREAM OF ZONE 2
- ASSURES UNIFORM SAMPLE FLOW

  $\Delta Ps = 10\,\Delta Pa$

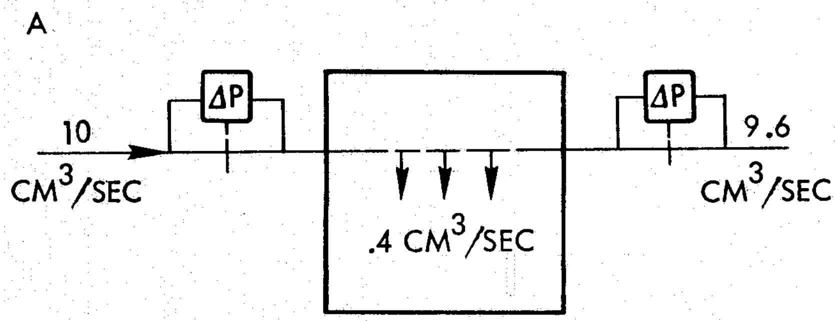
- ASSURES DECAY OF SAMPLE VELOCITY PERTURBATION
- ACCEPTABLE DIFFUSION LOSSES IN SLIT

TRW SYSTEMS GROUP

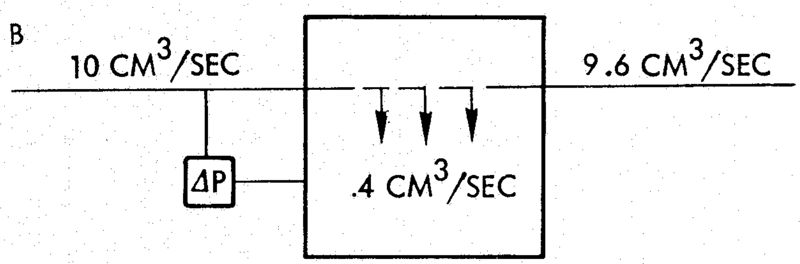
Two alternate concepts have been investigated for accurate sample flow measurement with control of the aerosol diffusion losses. Both are based on passing a large sample flow through the sample tube and bleeding only a small portion of it into the CFD chamber.

Both schemes, however, introduce new problems which make their implementation impractical.

SAMPLE ENTRY SUBASSEMBLY
ALTERNATE CONCEPTS FOR MEASUREMENT WITH AEROSOL LOSS CONTROL



- UTILIZE AUGMENTED FLOW TO REDUCE AEROSOL LOSS IN LINES. BLEED A SMALL PORTION OF FLOW THROUGH SLIT. MEASURE FLOW IN AND OUT.
- PROBLEMS:
  1) CANNOT ACHIEVE 1 PERCENT ACCURACY IN SAMPLE FLOW. f IS THE DIFFERENCE BETWEEN TWO LARGE NUMBERS
  2) SAMPLE IS DRAWN FROM AEROSOL DEPLETED BOUNDARY LAYER



- MEASURE FLOW ACROSS CALIBRATED SAMPLE ENTRY SLIT.
- PROBLEMS:
  1) LARGE ENOUGH ΔP FOR ACCURATE FLOW MEASUREMENT RESULTS IN EXCESSIVE DIFFUSION LOSS THROUGH SLIT AND SAMPLE ENTRANCE VELOCITY.
  2) SAMPLE IS DRAWN FROM AEROSOL DEPLETED BOUNDARY LAYER.

TRW SYSTEMS GROUP

The table on the facing page summarizes the internal configuration and sample entry parameters for the recommended design.

SUMMARY OF RECOMMENDED CFD DESIGN PARAMETERS
INTERNAL CONFIGURATION AND SAMPLE ENTRY

- DIMENSIONS

LENGTH OF ZONE 1		17.3 CM
LENGTH OF ZONE 2		34.5 CM
TOTAL LENGTH		51.8 CM
PLATE SPACING		1.5 CM
WIDTH OF CHAMBER		30 CM
POSITION OF SAMPLE SLIT		14.3 CM
LENGTH OF SAMPLE SLIT		12 CM
HEIGHT OF SAMPLE SLIT		0.0052 CM
THICKNESS OF SAMPLE SLIT		0.00127 CM
INTERNAL DIMENSIONS OF SAMPLE ENTRY CHANNEL		0.4 X 1.2 CM

- FLOW RATES

CARRIER FLOW RATE (≥20% PLATEAU)		15-83 CM^3/SEC
SAMPLE FLOW RATE (CONSTANT f_s DESIGN)		0.4 CM^3/SEC
MAXIMUM DROPLET FLOW ($S'_M/S_M = 0.99$)	0.1% S_M	192 DROPS/SEC
	0.5% S_M	470 DROPS/SEC
	≥1% S_M	885 DROPS/SEC

TRW SYSTEMS GROUP

The requirements and objectives considered in designing the CFD wicking system are as shown.

Although no longer a requirement, vertical operation of the CFD during ground based testing will yield results more representative of zero-g performance. Thus, our recommended design provides this capability.

CFD WICKING SYSTEM

REQUIREMENTS AND OBJECTIVES:

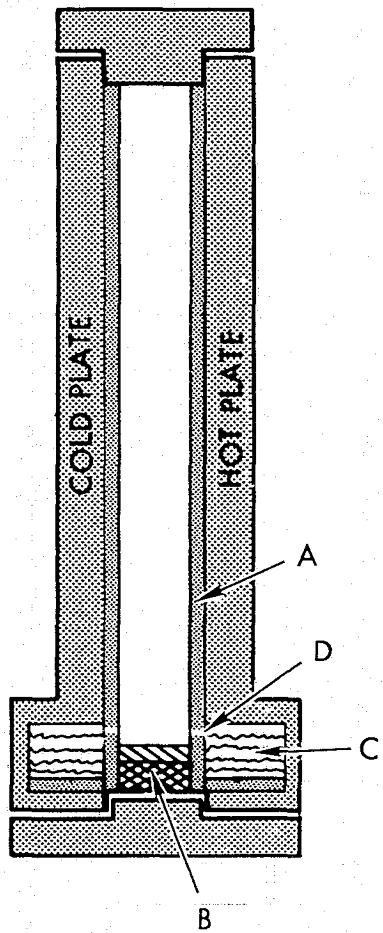
- MINIMUM TEMPERATURE DROP ACROSS WICKS
- STORE SUFFICIENT WATER FOR OPERATION OVER ENTIRE MISSION
- MINIMIZE INFLUENCE OF CAPILLARITY ON VAPOR PRESSURE (S_M)
- OPERATE BY SAME MECHANISM IN BOTH ZERO-G AND ONE-G WITH VERTICAL ORIENTATION

TRW
SYSTEMS GROUP

The wicking system incorporates the features shown on the facing page.

It is necessary to launch the ACPL with all wick systems dry (in the CFD, Saturator and SDL) and to fill them in orbit. Water storage reservoirs are included in each case to allow a single fill operation to suffice for an entire mission.

RECOMMENDED WICKING SYSTEM



A) SINTERED METALLIC WICKS DIFFUSION BONDED TO PLATES ASSURES ACCURACY OF TEMPERATURE MEASUREMENT (UNCERTAINTY IN $\Delta T < 0.001\,°C$)

B) LOW CONDUCTIVITY FIBER WICK TO TRANSFER WATER BETWEEN PLATES – ISOLATED FROM AIR FLOW

C) GRADED POROSITY WICKS TO CONTROL WATER LOCATION IN STORAGE RESERVOIRS. 80 CM^3 STORAGE VOLUME PROVIDES 50 PERCENT CONTINGENCY FOR CONTINUOUS OPERATION OVER 48 HOURS

D) VENTS TO CHAMBER MAKE WICKING SYSTEM INSENSITIVE TO CHAMBER PRESSURE

TRW SYSTEMS GROUP

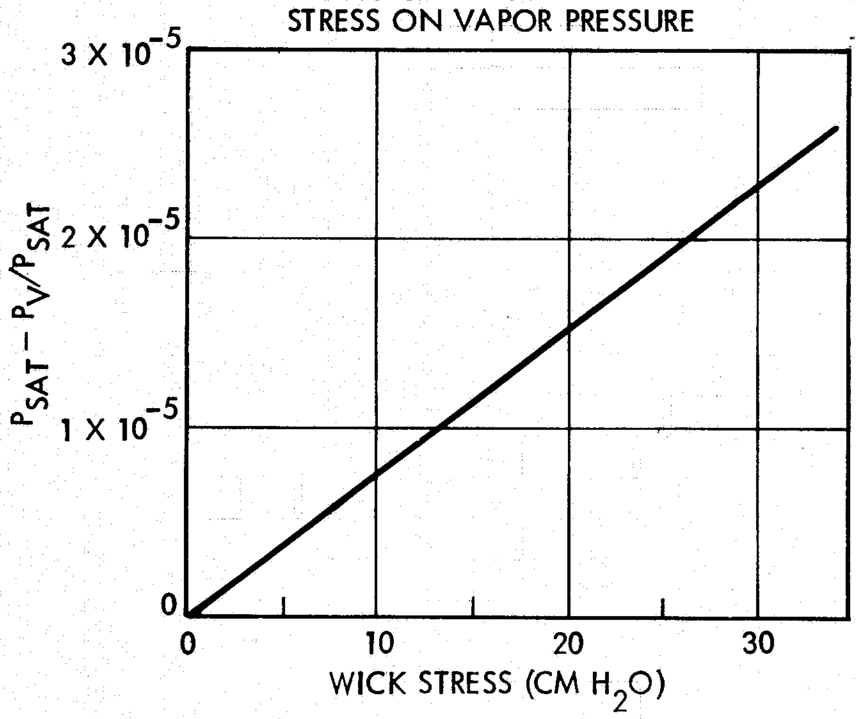
The capillary stress in the wicks necessary to pump water and to support the hydrostatic head during terrestrial operation results in a reduction of the water vapor pressure. This leads to an uncertainty in the maximum supersaturation seen by the sample due to the variation of wick stress along the sample slit.

The maximum uncertainty will be less than 0.04 percent of the supersaturation for o-g operation and less than 1.0% for 1-g operation in the vertical mode.

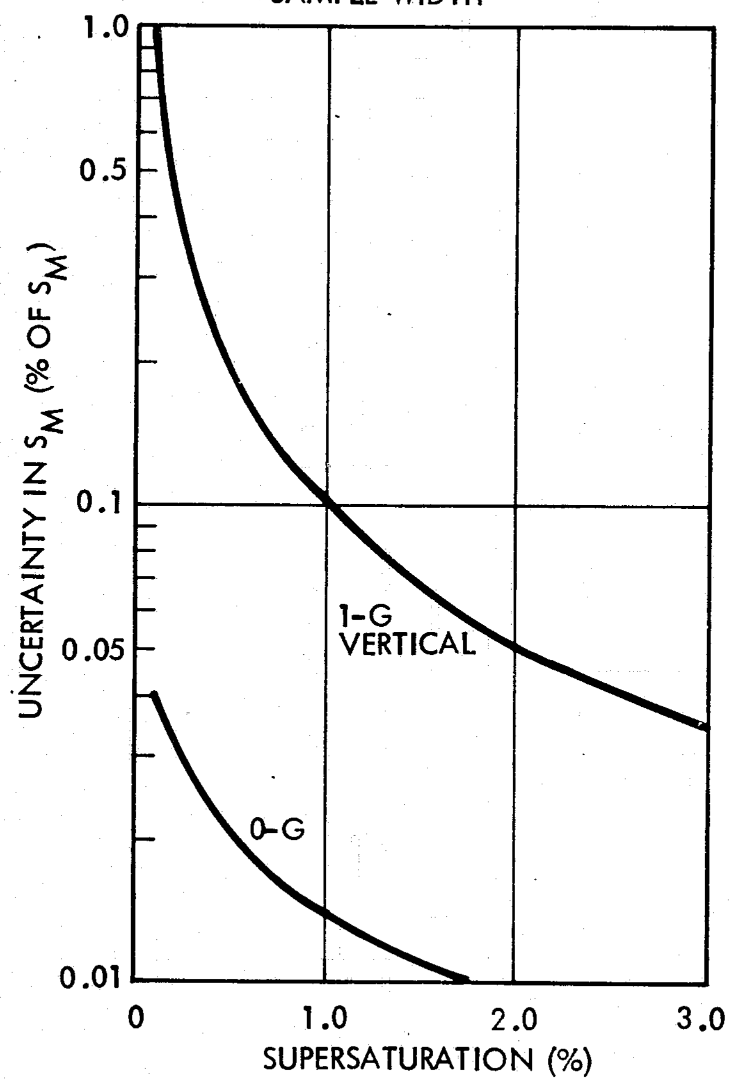
EFFECTS OF CAPILLARY STRESS

SINTERED WICK:	FIBER DIAMETER	–	0.0013 CM
	POROSITY	–	80%
	THICKNESS	–	0.0254 CM
MAXIMUM CAPILLARY PRESSURE		–	58 CM H_2O
MAXIMUM WICK STRESS:	ZERO-G	–	3 CM H_2O
	ONE-G	–	33 CM H_2O

EFFECT OF CAPILLARY STRESS ON VAPOR PRESSURE



UNCERTAINTY IN S_M DUE TO VARIATION IN WICK STRESS OVER SAMPLE WIDTH



Thermal control of the CFD has been designed to meet the requirements and objectives listed. Although not specifically stated as requirements in the Level I Specification, dew point control of the sample, carrier and CFD outlet flow is necessary in order to meet the stated requirements.

THERMAL CONTROL

REQUIREMENTS AND OBJECTIVES:

• OPERATING TEMPERATURE RANGE	$0.5 \le T_M \le 25°C$
• RELATIONSHIP BETWEEN T_M AND CLOUD ACTIVATION TEMPERATURE FOR $0.1 \le S_M \le 1.0\%$	$T_{ACT} \le T_M \le T_{ACT} + 3°C$
• TEMPERATURE MEASUREMENT ACCURACY	±0.1°C
• ΔT STABILITY AND MEASUREMENT ACCURACY	±0.01°C
• PLATE TEMPERATURE UNIFORMITY IN ACTIVATION AND GROWTH REGION	±0.01°C
• RANGE IN ΔT: $0.05 \le S_M \le 3.0\%$	1.12 - 8.66°C
$0.1 \le S_M \le 1.0\%$	1.58 - 5.00°C

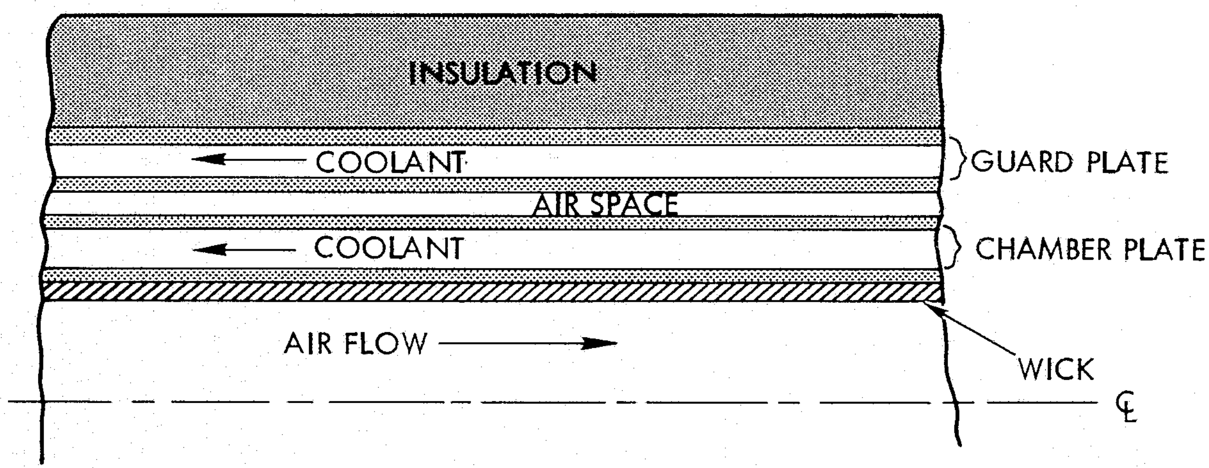
- DEW POINT OF SAMPLE BELOW T_M (CONDENSATION IN SAMPLE TUBE)
- DEW POINT OF CARRIER AIR BELOW T_H (CONDENSATION ON DRY HOT PLATE)
- T_M BELOW AMBIENT (CONDENSATION IN OPC)

TRW
SYSTEMS GROUP

The thermal control scheme selected incorporates pumped fluid in counterflow to the air stream as described at Concept Review. However, temperature controlled guard plates have been added to isolate the system from ambient heat leaks and provide better uniformity.

THERMAL CONTROL APPROACH

- PUMPED FREON IN COUNTERFLOW TO AIR STREAM PROVIDES MAXIMUM CONTROL IN CRITICAL REGION AND TEMPERATURE STABILITY
- TEMPERATURE CONTROLLED GUARD PLATES ISOLATE INTERNAL CHAMBER FROM AMBIENT
- THERMAL MODELLING SHOWS UNIFORMITY REQUIREMENTS CAN BE MET
- MATCHED AND CALIBRATED THERMISTORS MEET MEASUREMENT REQUIREMENTS



TRW

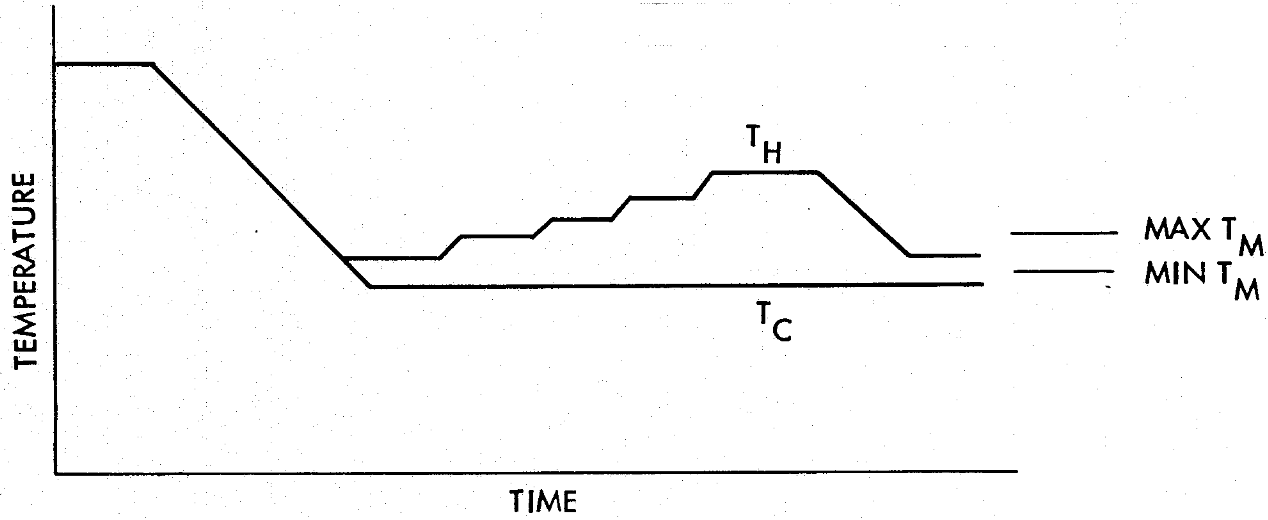
After cooldown to the desired temperature range the CFD will be operated with the cold plate held constant and the hot plate stepped using the hot fluid injection scheme described at Concept Review. The Thermal Control Subsystem will monitor and control the temperature of the cold plate and the temperature difference between the plates.

The total range in mean temperature will be 1.7°C over the primary range in supersaturation. This provides considerable margin on meeting the requirement that $T_{ACT} \leq T_M \leq T_{ACT} + 3°C$.

Local drying of the sample and carrier flow will be necessary for condensation control when an experiment calls for a cloud activation temperature much below the saturator temperature.

The design of the CFD and Thermal Control Subsystem has been based on a total period of 15 minutes to characterize an aerosol. An average of about 2 minutes per point will be required (longer at low S_M and shorter at high S_M) of which 30 seconds will be necessary to alter the hot plate temperature and air flow rates.

TEMPERATURE AND DEW POINT CONTROL



- AFTER COOLDOWN HOLD T_C CONSTANT AND STEP T_H
- CONTROL AND MONITOR T_C AND ΔT
- COOLDOWN RATE ≥ 0.4°C/MIN
- T_H STEPPING RATE ≥ 2.0°C/MIN
- $T_{ACT} \leq T_M \leq T_{ACT} + 1.7$°C FOR $0.1 \leq S_M \leq 1.0\%$ AND MIN $T_M = T_{ACT}$
- $T_{ACT} < T_{SAT}$ DEPENDING ON INITIAL R.H. IN EXPANSION CHAMBER
- SAMPLE DEW POINT $= T_{SAT}$; SAMPLE MUST BE DRIED FOR $T_{ACT} < T_{SAT} - 1.3$°C
- CARRIER DEW POINT $\approx T_{SAT} - 1.5$°C, $T_H \geq T_M + 0.8$°C; CARRIER FLOW MUST BE DRIED FOR $T_{ACT} < T_{SAT} - 3.7$°C
- INCLUDE DIFFUSION DRIERS IN SAMPLE AND CARRIER FLOW LINES

TRW
SYSTEMS GROUP

PRECEDING PAGE BLANK NOT FILMED

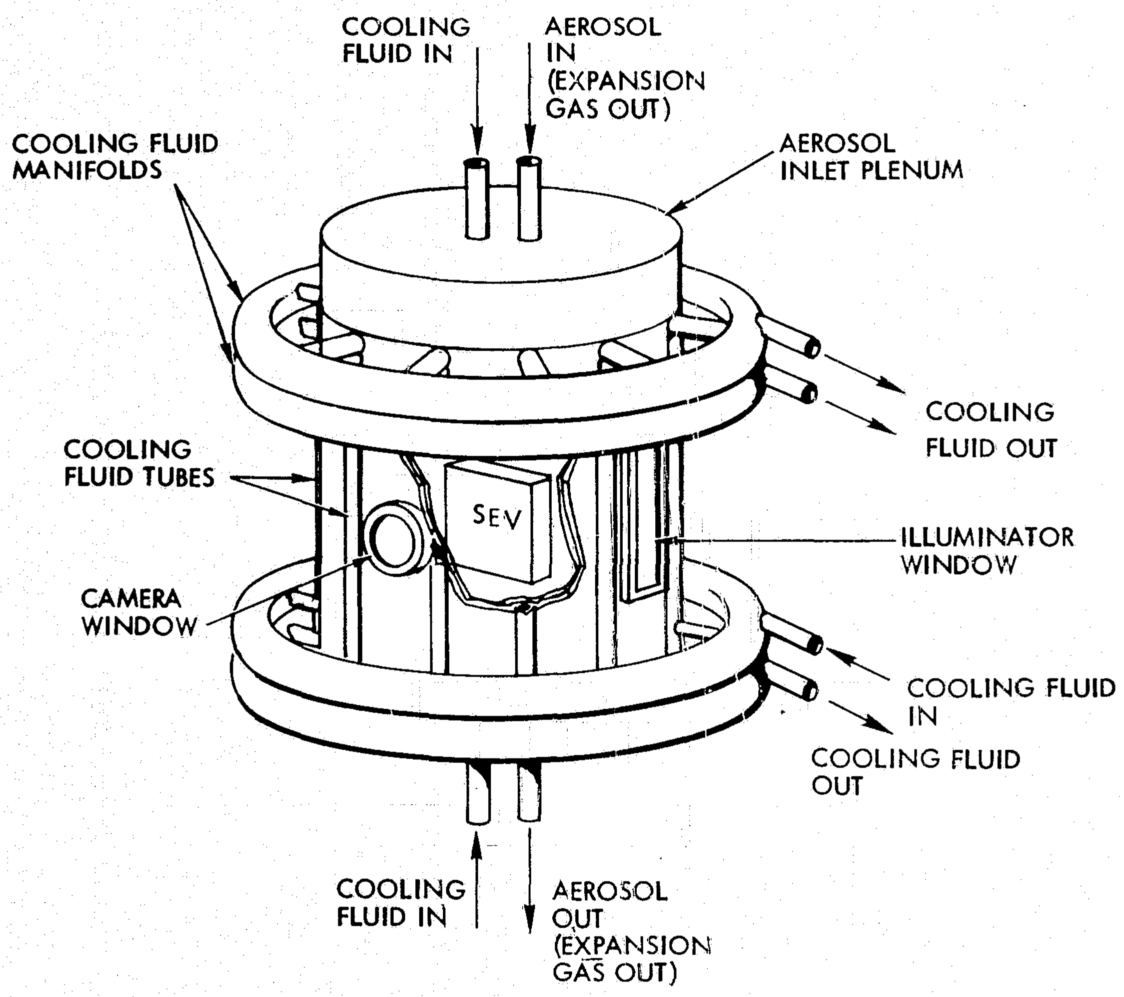
EXPANSION CHAMBER SUBSYSTEM

TRW SYSTEMS GROUP

The vertical SEV orientation is chosen for the following reasons:

- Mechanical design and fabrication is greatly simplified by having all optical windows in the cylindrical side walls rather than the circular end walls.
- Thermal control trade studies (presented at Concept Review) have shown that the thermal uniformity advantages of orienting the SEV in a "horizontal" position are quite marginal, and may be overwhelmed by nonuniformities in wall temperature due to windows and ports.

EXPANSION CHAMBER SUBSYSTEM



- DIMENSIONS

  CHAMBER 35 CM DIA X 33 CM
  SEV 10 CM X 7 CM X 1.5 CM

- THERMAL CONTROL CONCEPT

  DOUBLE, INSULATED WALL WITH PUMPED FLUID LOOPS AND ZONED TRIMMER HEATERS

- AEROSOL SAMPLE INJECTION

  TURBULENT JETS (APPROXIMATELY 50 HOLES)

- EXPANSION GAS WITHDRAWAL

  THROUGH AEROSOL INJECTION PORTS

- POWER CONSUMPTION

  FOR 6°C/MINUTE EXPANSION
  STARTING AT 20°C 384W
  STARTING AT 6°C 919W

TRW SYSTEMS GROUP

EXPANSION CHAMBER THERMAL CONTROL CONCEPTUAL TRADES

- ASPECT RATIO CONSIDERATIONS
- WALL THERMAL CONTROL
- WINDOW THERMAL CONTROL

Expansion chamber thermal control requirements involve maintaining the walls of the chamber at a very uniform and precise temperature under steady state conditions and for various chamber cooldown transients. In addition to chamber wall requirements, which can be demonstrated by measurement, there is a requirement for SEV uniformity which will be confirmed by analysis.

EXPANSION CHAMBER THERMAL CONTROL REQUIREMENTS

STEADY STATE WALL TEMPERATURE: ANY SPECIFIED VALUE BETWEEN 0.5 AND 20°C TO PRECISION OF ±0.1°C

CHAMBER COOLDOWN RATES:

- SPECIFIED RATES, TIMES AND TEMPERATURES

dT/dτ [°C/MIN]	0.5	1.2	6.0
[TIME MIN]	60	30	1
TEMPERATURE RANGE [°C]	20 TO -25	20 TO -15	20 TO 0

- FOR RATES ≤ 3.0°C/MIN TRACK SPECIFIED RATE WITHIN ±0.1°C
- CHANGE COOLDOWN RATE BETWEEN ANY TWO VALUES BEFORE TEMPERATURE HAS CHANGED MORE THAN 0.5°C

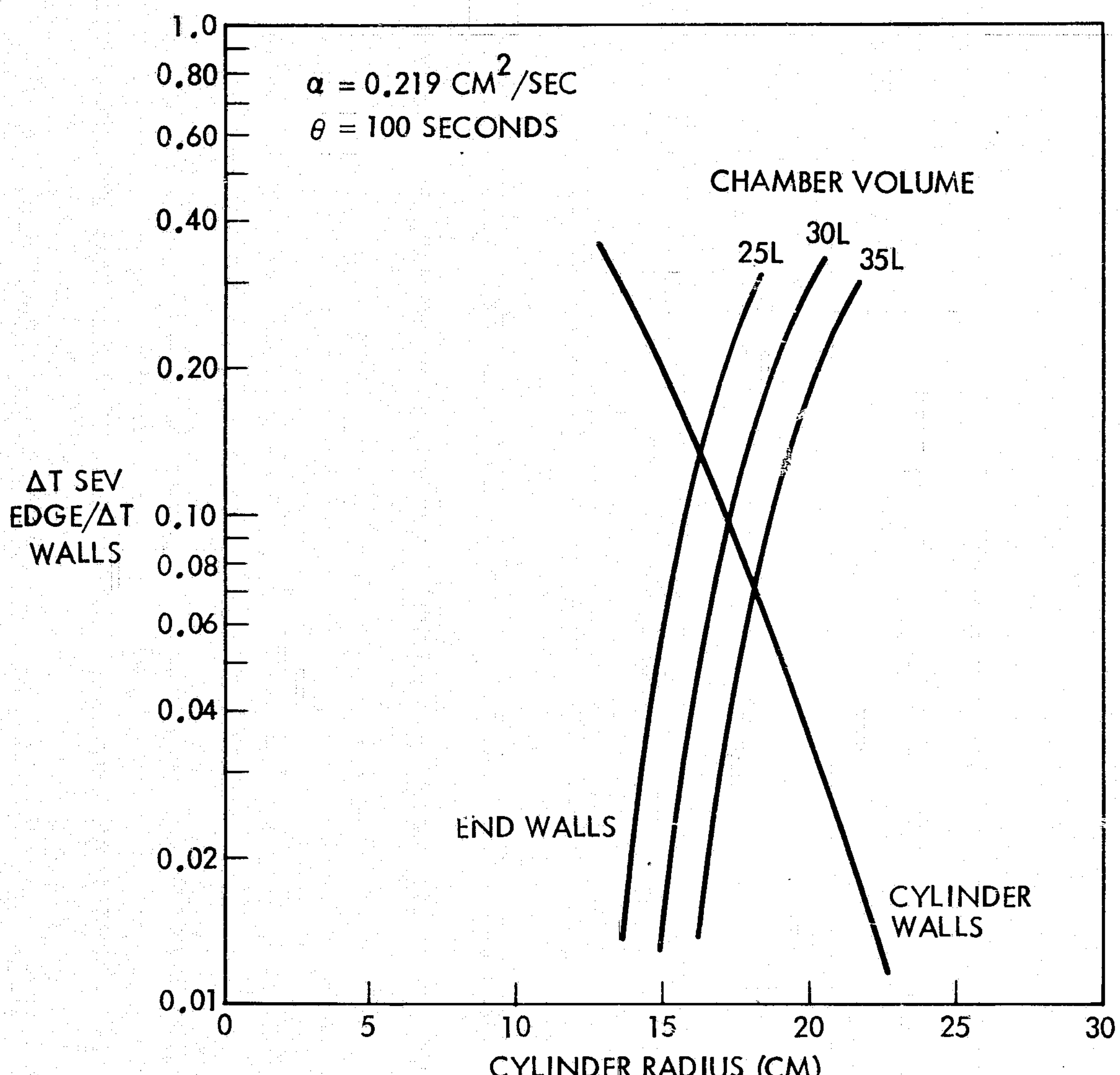
CHAMBER WALL UNIFORMITY DURING COOLDOWN: 90 PERCENT OF CHAMBER WALL WITHIN ±0.1°C OF MEAN TEMPERATURE FOR RATES ≤3°C/MIN

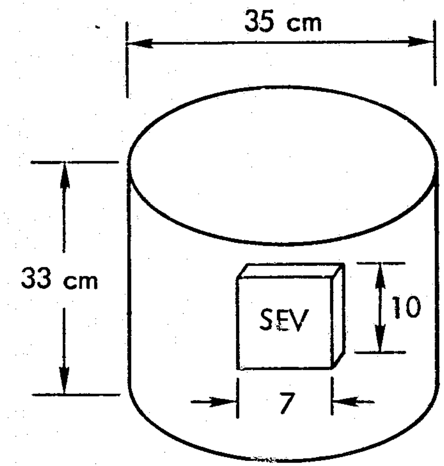
SEV UNIFORMITY: ±0.005°C DURING ACTIVATION PERIODS UP TO 100 SECONDS

TRW
SYSTEMS GROUP

The influence of wall temperature on SEV temperature as a function of chamber geometry is shown on this chart. The selected geometry is one where the effect of end and side walls is equal.

EXPANSION CHAMBER WALL TEMPERATURE INFLUENCE ON SEV



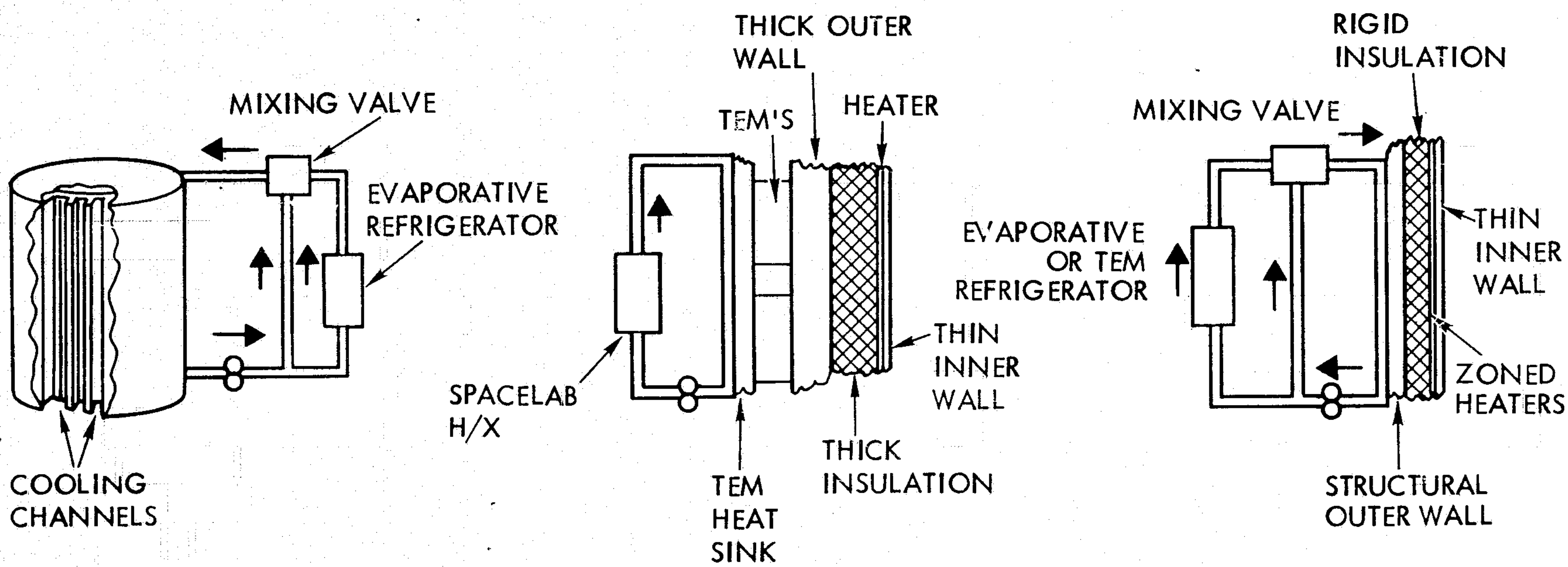


SELECTED GEOMETRY

TRW SYSTEMS GROUP

Three basic chamber cooling concepts are being evaluated. The first uses direct cooling by flowing liquid through channels in the chamber wall. The two remaining concepts incorporate a double wall with insulation between the walls to reduce inner wall gradients. Two variations of the double wall concept were investigated. The first has a relatively thick insulation and refrigeration is stored by pre-chilling the outer wall. The second variation uses a much thinner insulation and does not have storage of refrigeration in the outer wall. All three designs are discussed in detail in the following viewgraphs.

EXPANSION CHAMBER THERMAL CONTROL CONCEPTS INVESTIGATED



SINGLE WALL WITH COUNTERFLOW PUMPED FLUID LOOP

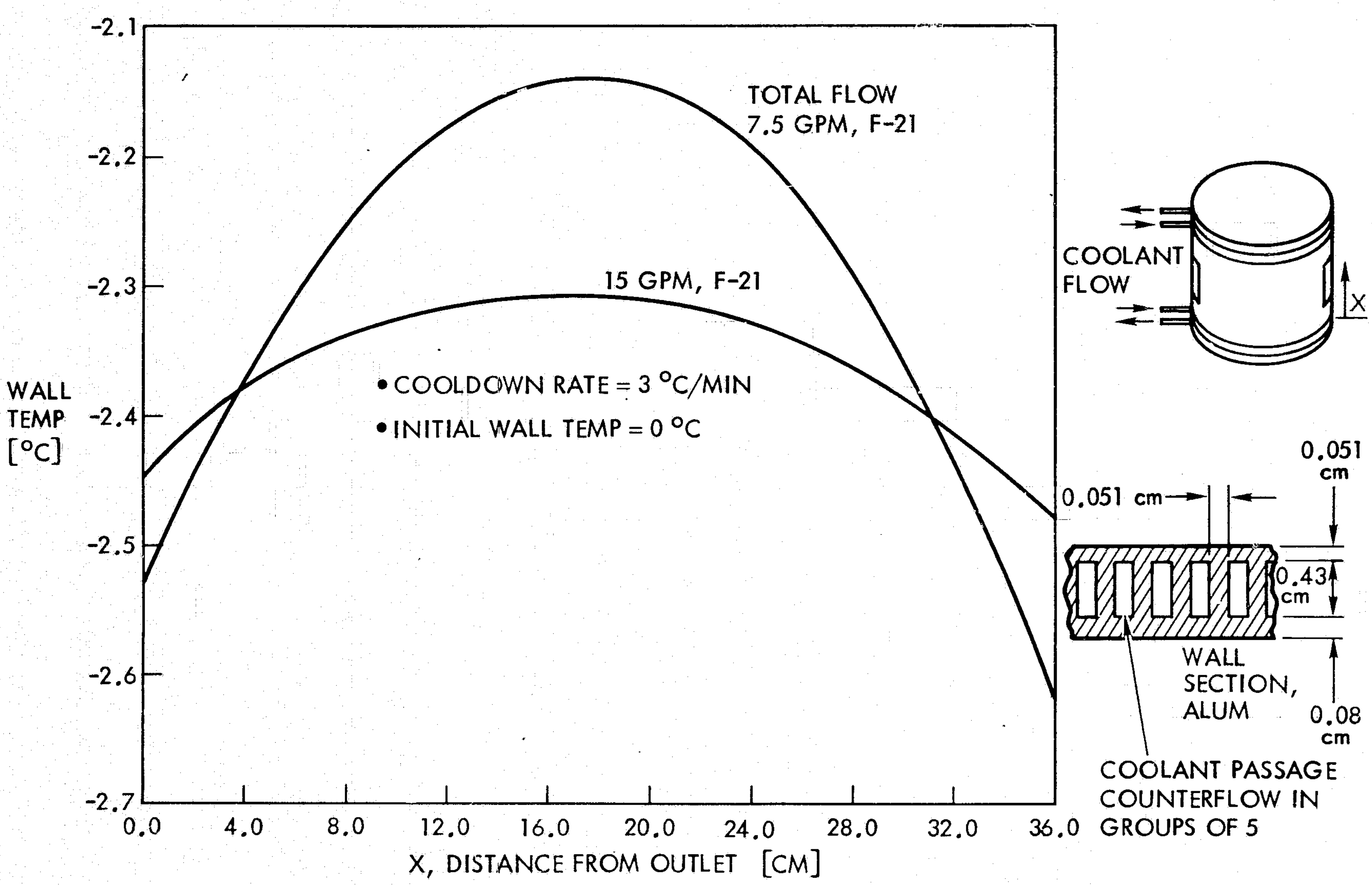
WALL-STORED REFRIGERATION WITH INTEGRAL TEM'S

INSULATED WALL WITH ZONED TRIMMER HEATER

TRW SYSTEMS GROUP

Analysis results for a single wall design where cooling channels are integral to the wall. Small width channels are used to minimize entrance region effects and the coolant is run in counter flow. Results of the analysis show that approximately 15 gallons per minute of F-21 would be required to meet the temperature uniformity requirement of $\pm$ 0.1°C at a cooling rate of 3°C per minute.

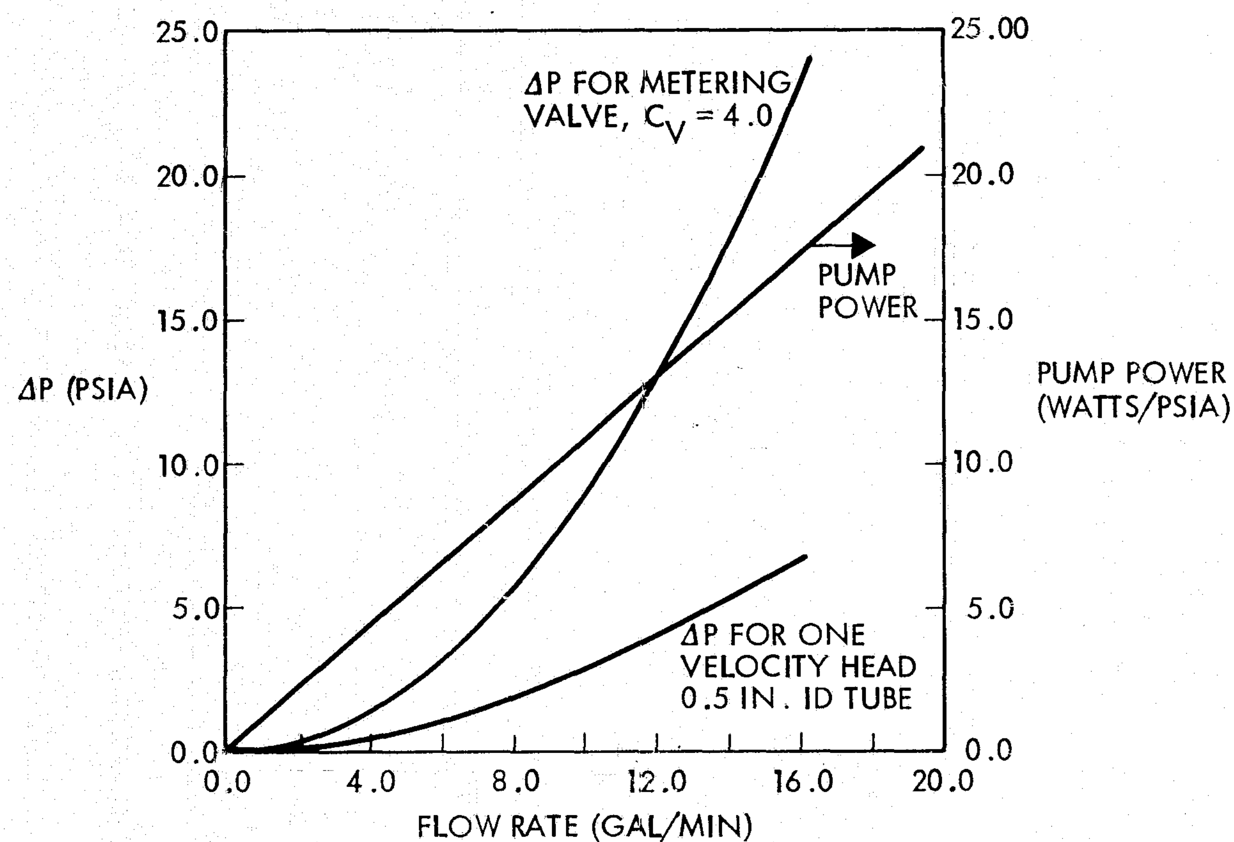
SINGLE WALL TEMPERATURE PROFILES



TRW SYSTEMS GROUP

Pump power estimates as a function of flow rate are shown in this chart. At the required flow rate of 15 GPM Freon 21 for the single wall concept an excessive pump power is required.

PUMPING POWER CONSIDERATIONS
SINGLE WALL WITH PUMPED FLUID LOOP



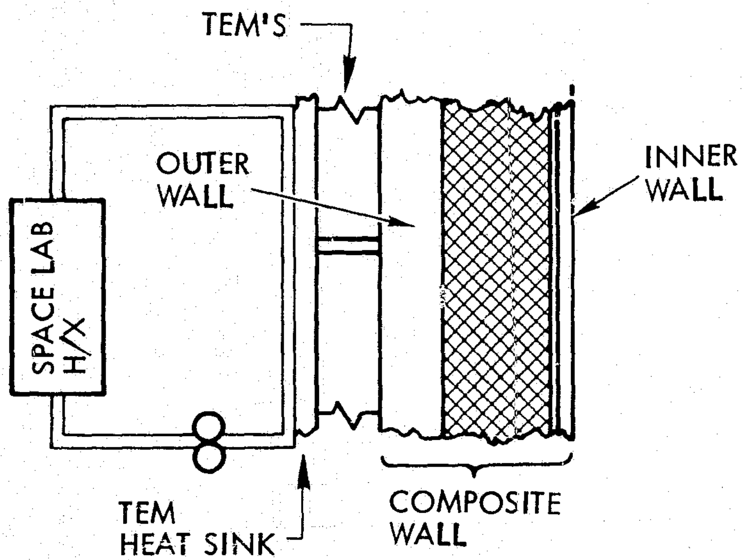
- F-21 FLUID
- PUMP/MOTOR EFF = 0.40
- EXAMPLE PUMP POWERS FOR 5 VELOCITY HEADS LOSS AND METERING VALVE C_V = 4.0

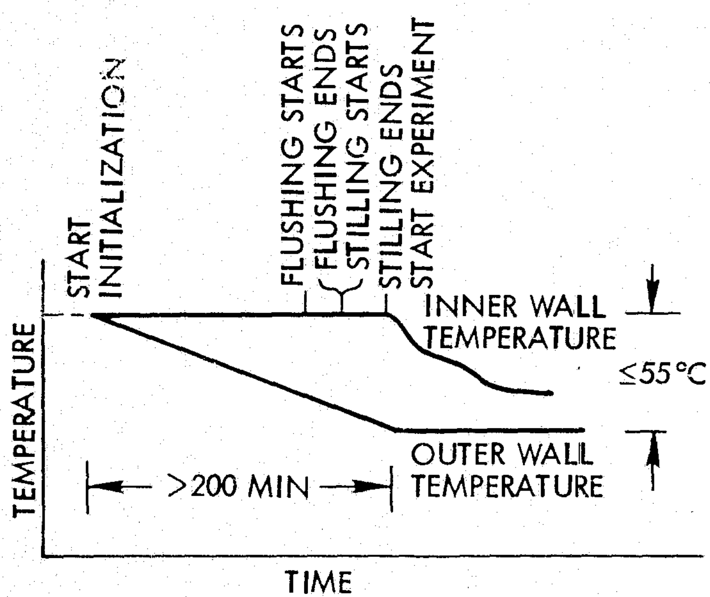
GPM	POWER (WATTS)
5.0	30
7.5	100
15.0	800

TRW SYSTEMS GROUP

The wall-stored refrigeration concept reduces thermal loads to the point where a thermoelectric refrigerator becomes practical. The initialization of the outer chamber wall temperature, which may be as much as 55°C below the inner wall temperature at the start of the experiment, is spread over several hours, thus time averaging the peak power requirement. Because of aerosol loss considerations, flushing and stilling must be carried out immediately prior to the start of the experiment.

WALL – STORED REFRIGERATION WITH INTEGRAL TEM'S





ADVANTAGES

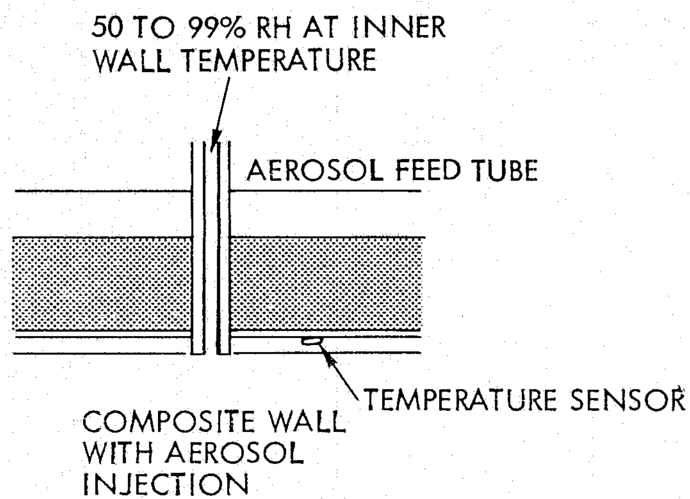
- COMPOSITE STRUCTURE PROVIDES GOOD UNIFORMITY WITH LOW THERMAL MASS INNER WALL, FAST RESPONSE
- INITIAL LOAD OF COOLING MASSIVE OUTER WALL CAN BE AVERAGED OVER LONG TIME
- HIGH THERMAL RESISTANCE OF INSULATION MINIMIZES STEADY STATE POWER CONSUMPTION
- USE OF DIRECT MOUNTED TEM'S ALLOWS USE OF WATER AS COOLING FLUID

TRW SYSTEMS GROUP

Since flushing occurs just before the start of the experiment, aerosol samples must be injected through the walls at times when the temperature of the outer wall can be far below the gas temperature. At 50% R.H. and room temperature, the injected aerosol can be cooled only about 11°C before the dew point is reached. Thus, the aerosol feed tubes may have to be heated to prevent unacceptable condensation in the sample. The resulting effect on thermal control of the wall may be unacceptable.

At the start of the expansion, the inner chamber wall is controlled by the integral heater. The wall and gas are in steady state thermal equilibrium. Thus, any large scale nonuniformity in wall temperature due to large scale nonuniformity in the heater or in the heater-wall bond will be felt to the fullest possible extent by the SEV. In extreme cases, the SEV may not meet the uniformity requirements (.005°C for the first 100 seconds) even at the start of the experiment.

WALL – STORED REFRIGERATION WITH INTEGRAL TEM'S



DISADVANTAGES

HIGH INITIAL ΔT BETWEEN INNER AND OUTER WALLS

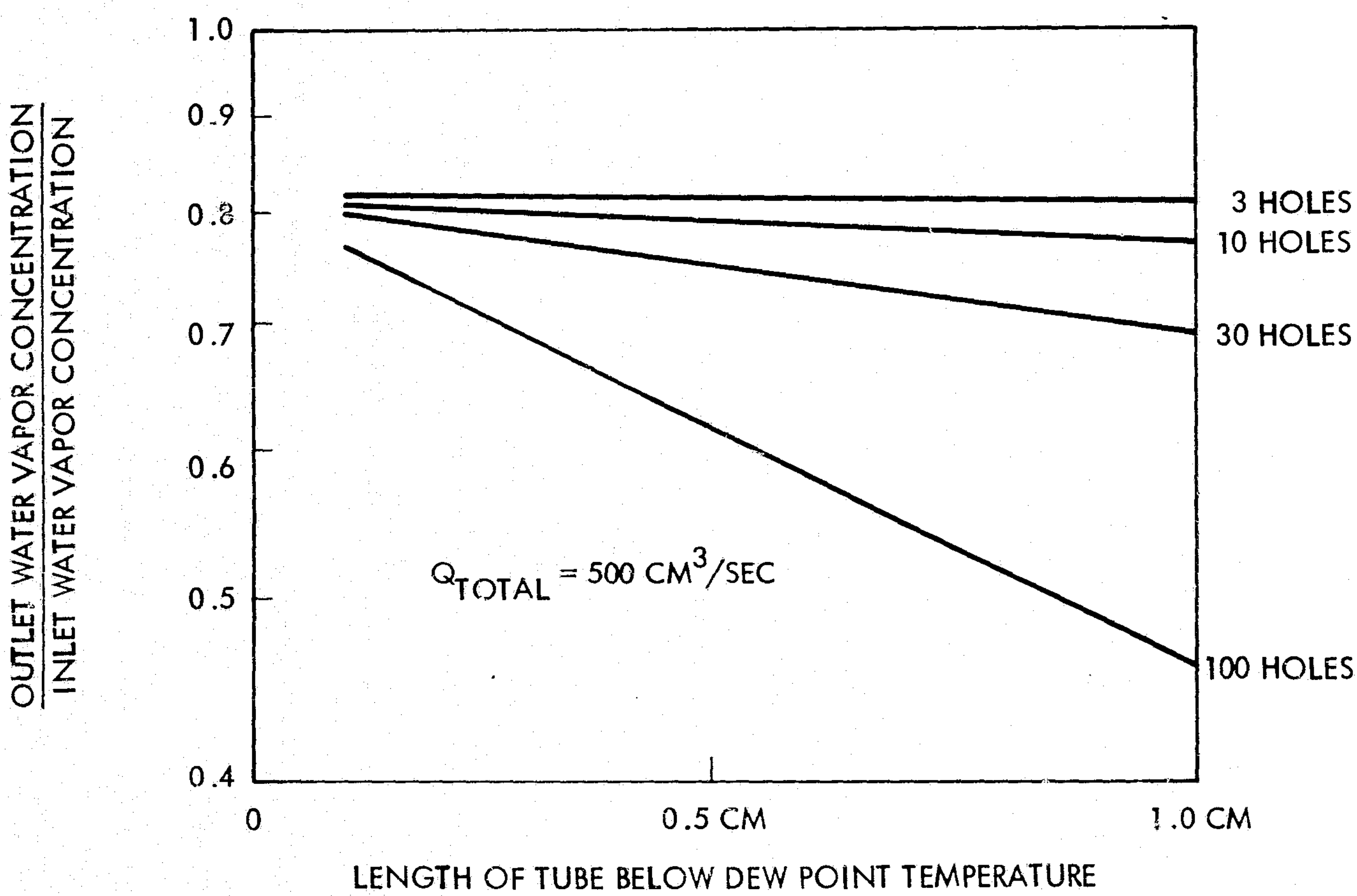
- VERY DIFFICULT TO MEASURE TEMPERATURES TO REQUIRED ACCURACY WITH LARGE ΔT ACROSS SENSOR
- TEMS MUST MAINTAIN OUTER WALL AT LOW TEMPERATURE, RESULTING IN LOW COP
- AEROSOL SAMPLE INJECTION THROUGH TOP AND BOTTOM PLATE COMPLICATED BECAUSE OF CONDENSATION WHILE PASSING OUTER WALL
- TEMPERATURE NONUNIFORMITY IN INNER WALL BECAUSE OF HEAT LEAKS THROUGH FEED TUBES
- DIFFICULT TO CONTROL WINDOW TEMPERATURES IF MOUNTED TO OUTSIDE (STRUCTURAL) WALL AT LOW TEMPERATURE

INITIAL UNIFORMITY OF WALLS (AND SEV) AT START OF EXPERIMENT LIMITED BY UNIFORMITY OF HEATER

TRW

The rate of loss of water vapor by diffusion to the walls of the aerosol feed tubes is shown here. The abscissa is the length of feed tube which is at or below the dew point of the aerosol sample. All calculations are based on a total volumetric flow rate of 500 cm^3/sec. The curves do not pass through unity (no aerosol loss) for a tube length of zero because the equations on which the calculations are based assume fully developed concentration and velocity profiles. Entrance effects, which occur over tube lengths $\ll .1$ cm, produce much larger aerosol losses and result in steeper curves passing through unity for zero tube length and connecting to the given curves, which are not shown here.

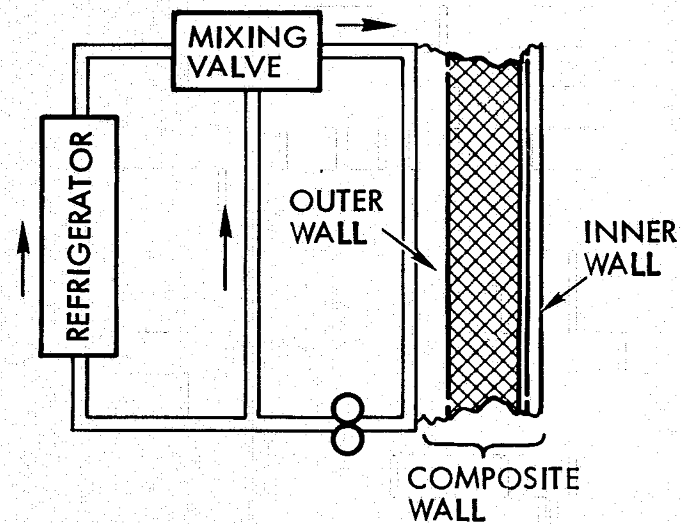
WALL – STORED REFRIGERATION WITH INTEGRAL TEMS
WATER VAPOR LOSS FROM AEROSOL SAMPLE

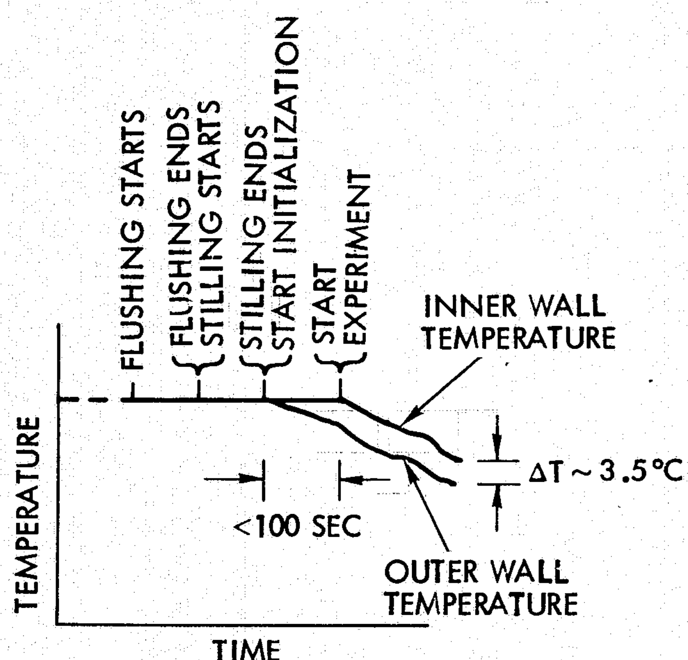


TRW SYSTEMS GROUP

By minimizing the temperature gradient between inner and outer walls of the expansion chamber, the difficulties encountered with the wall stored refrigeration concept are greatly reduced. Additionally, by reducing the time required for initialization of inner and outer wall temperatures, this approach allows flushing and stilling to occur before the initialization starts when the inner wall heaters are off and the wall temperatures are very uniform. Thus, inner and outer walls are at the same temperature and condensation in the feed tubes cannot take place. Furthermore, the time for initialization of the wall temperatures is shorter than the thermal equilibration time for the gas in the chamber, so that effects on SEV uniformity of large scale heater non-uniformities, which begin when the heaters are turned on at the start of wall temperature initialization, will be very small at the start of the actual expansion. In contrast, for the stored refrigeration approach, the gas is in steady state thermal equilibrium with the walls at the start of expansion so that large scale heater non-uniformities will produce larger SEV non-uniformities.

INSULATED WALL WITH ZONED TRIMMER HEATER



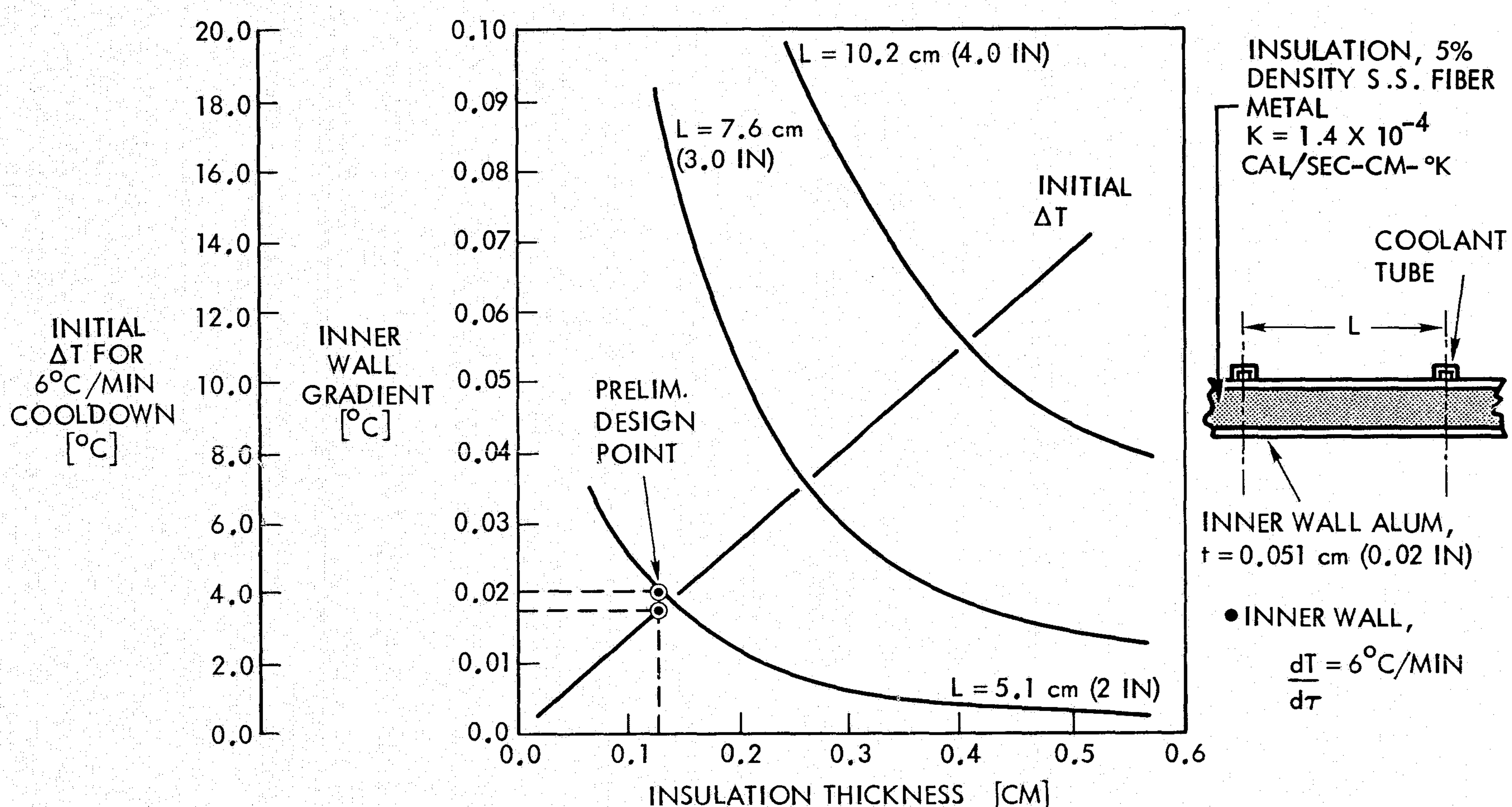


APPROACH

- MINIMIZE ΔT BETWEEN INNER AND OUTER WALLS TO REDUCE PROBLEMS
  - LOW THERMAL MASS OF OUTER WALL ALLOWS OUTER WALL TO TRACK REQUIRED CURVE WITH SOME ERROR
  - MODERATE RESISTANCE INSULATOR ATTENUATES TEMPERATURE NONUNIFORMITIES
  - LOW THERMAL MASS INNER WALL WITH ZONED TRIMMER HEATER REDUCES NONUNIFORMITIES TO ACCEPTABLE LEVEL (±0.1°C)
- REDUCE TIME TO START EXPERIMENT SO THAT THERMAL INITIALIZATION TIME IS SMALLER THAN TIME FOR EQUILIBRATION OF GAS TEMPERATURE WITHIN CHAMBER
  - ALLOWS FLUSHING AND STILLING WITH WALL HEATERS OFF, IMPROVES INITIAL UNIFORMITY OF SEV
- REMOVE SOURCE OF REFRIGERATION FROM EXPANSION CHAMBER WALLS, COUPLE WITH PUMPED FLUID LOOP
  - REDUCES CHANCE OF A SINGLE POINT FAILURE IN ONE TEM DEGRADING WALL UNIFORMITY

The use of insulation between an inner temperature controlled wall and an outer wall where cooling is applied directly results in a very uniform inner wall temperature. This viewgraph shows inner wall temperature gradients as a function of insulation thickness and spacing between coolant tubes on the outer wall. The design chosen is 0.127 cm of 5% density sintered stainless steel fiber metal which results in a 0.02°C temperature ripple. This is much less than the requirement of $\pm$ 0.1°C at 3°C/min and leaves margin for insulation and heater nonuniformity, window effects, and effect of heater and thermistor leads.

INSULATION THICKNESS EFFECTS

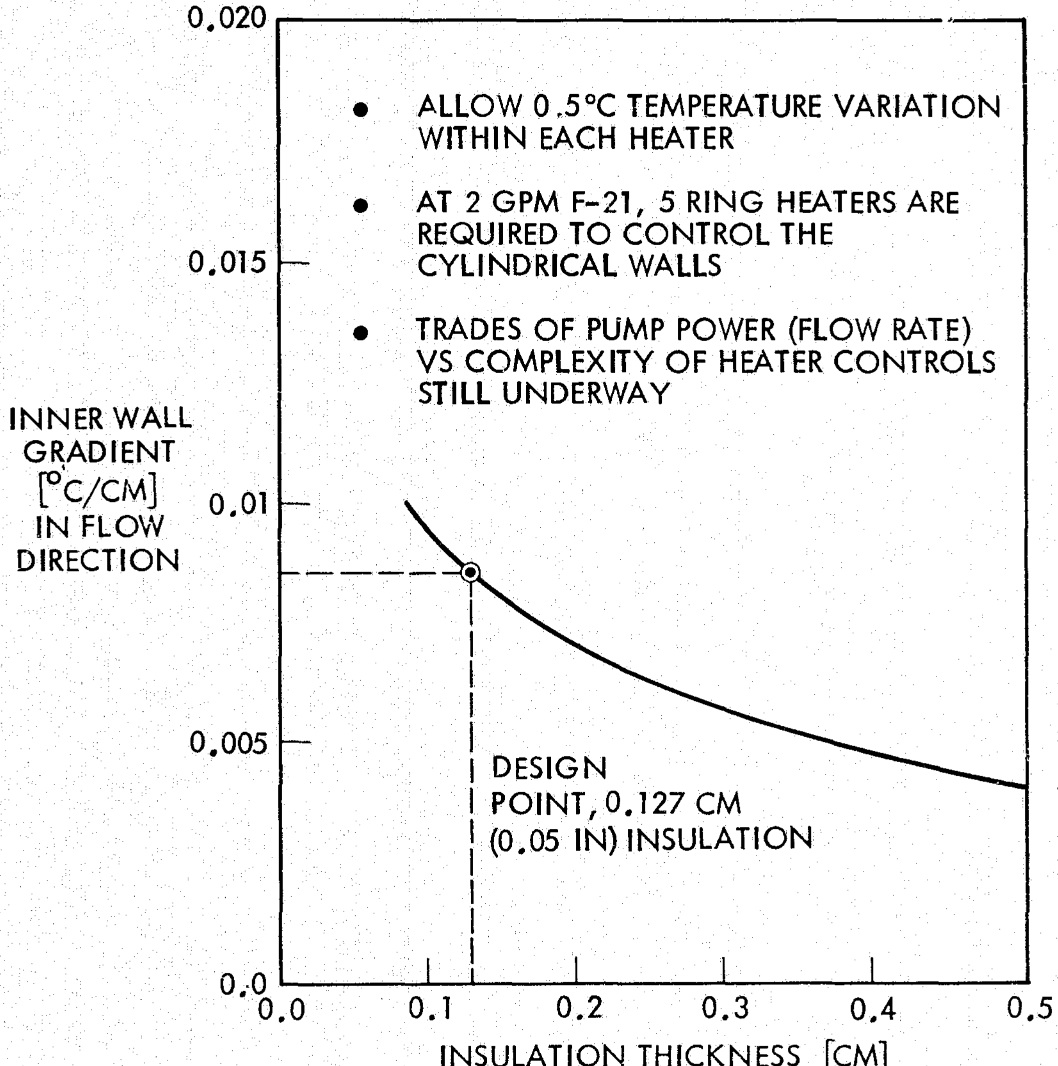


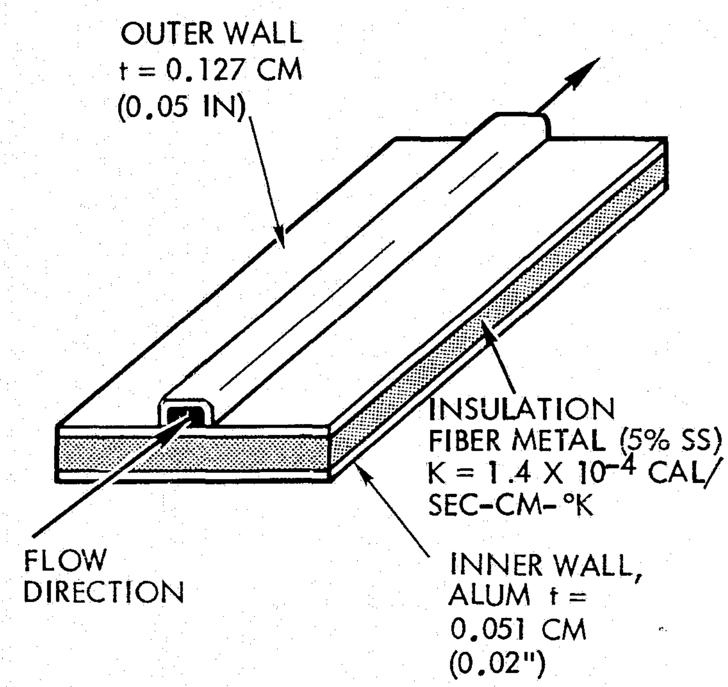
- INNER WALL, $\frac{dT}{d\tau} = 6°C/MIN$

TRW SYSTEMS GROUP

The insulation between inner and outer walls also reduces temperature gradients in the inner wall which are caused by temperature rise in the fluid. The design insulation thickness of 0.127 cm gives an inner wall gradient of .0085°C/cm due to the fluid temperature rise. Five heater circuits, each 6.6 cm long are presently anticipated to give a temperature gradient of .056°C across each heater.

LONGITUDINAL TEMPERATURE GRADIENT IN INSULATED DESIGN

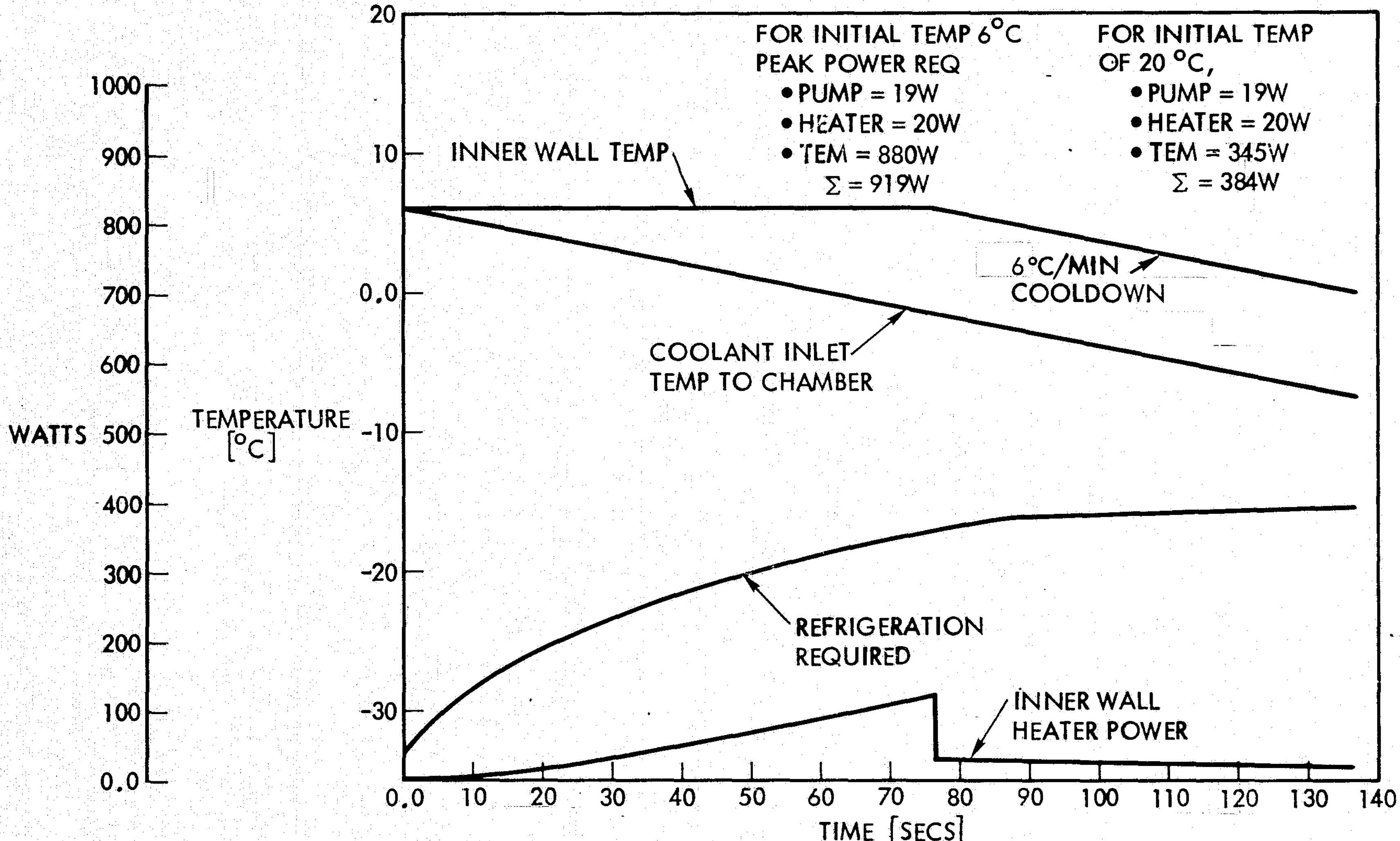




- INNER WALL, $\frac{dT}{dt} = 6$ °C/MIN
- TOTAL CHAMBER FLOW RATE = 2 GPM, F-21

For the insulated wall concept, the coolant inlet temperature to the chamber is first decreased at a rate equal to the desired wall cooldown rate while the inner wall temperature is held constant through the use of electrical heaters. When sufficient temperature difference is achieved between inner and outer walls to assure the inner wall will cool at the desired rate the heater powers are reduced and the experiment is started. In the example case 76 seconds of pre-chilling are required. Estimated total peak powers are given if thermoelectric cooling is used.

EXPANSION CHAMBER COOLDOWN TRANSIENT



TRW
SYSTEMS GROUP

The preferred approach, described in more detail in the remainder of this section, is the insulated wall with zoned trimmer heaters.

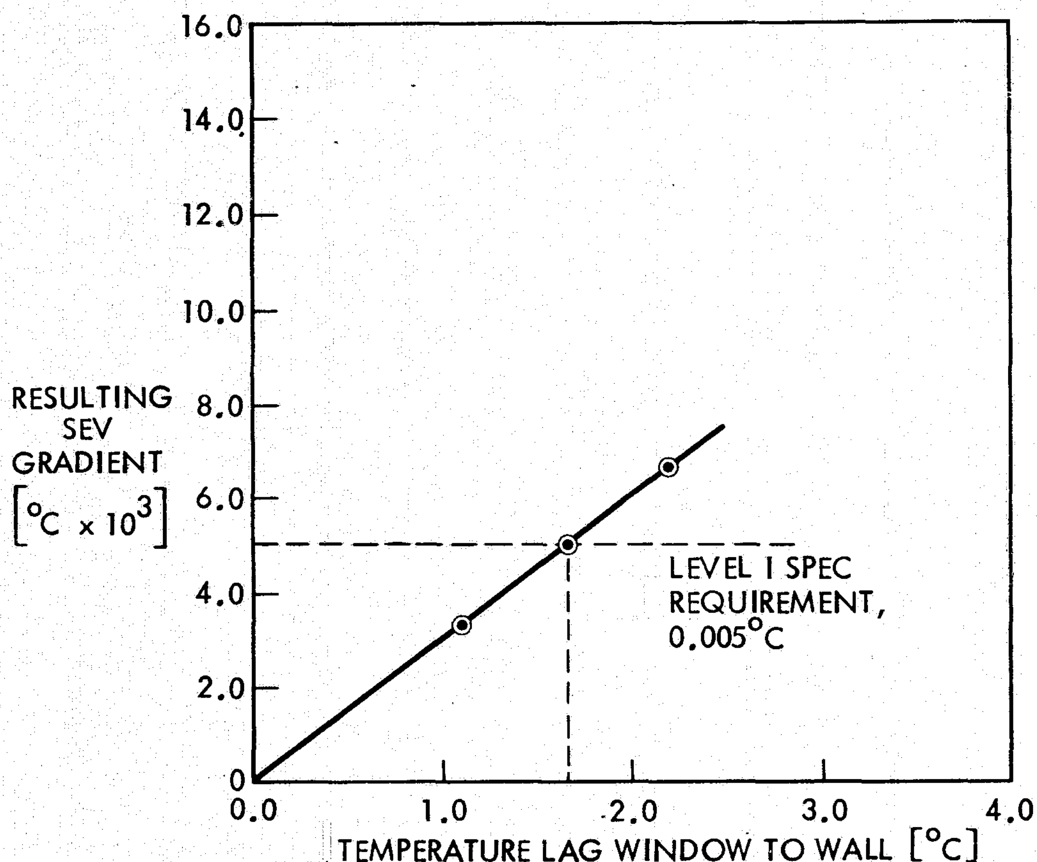
EXPANSION CHAMBER THERMAL CONTROL CONCEPT TRADE SUMMARY

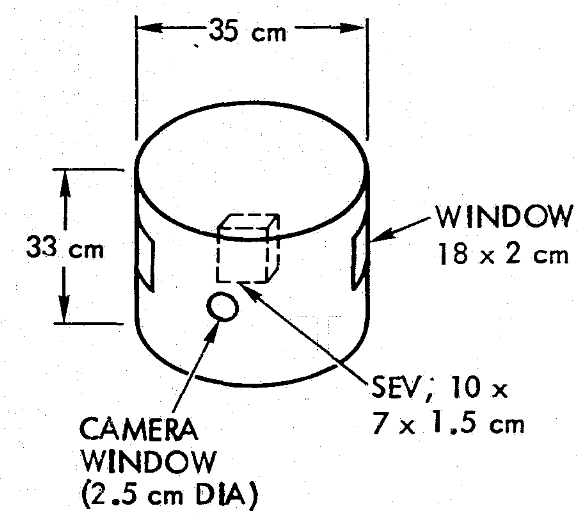
APPROACH	ADVANTAGES	DISADVANTAGES
SINGLE WALL WITH PUMPED FLUID LOOP	• SIMPLICITY OF CONCEPT • MOST HISTORY	• HIGH PUMP POWER AND LARGE LIQUID LOOP COMPONENTS • COMPLEXITY OF MECHANICAL FABRICATION • LARGE COOLING RATES REQUIRE EVAPORATIVE REFRIGERATOR WHICH NEEDS DEVELOPMENT
WALL-STORED REFRIGERATION WITH INTEGRAL TEM'S	• RAPID RESPONSE • REDUCED POWER CONSUMPTION • GOOD WALL UNIFORMITY • USES WATER TO COOL TEM HEAT SINK	• UNACCEPTABLY LARGE ΔT BETWEEN INNER AND OUTER WALLS LEADS TO SAMPLE CONDENSATION • INITIAL UNIFORMITY OF SEV AT START OF EXPANSION MAY NOT BE ACCEPTABLE
INSULATED WALL WITH ZONED TRIMMER HEATER	• RAPID RESPONSE • GOOD WALL UNIFORMITY • IMPROVED SEV UNIFORMITY AT START OF EXPANSION • REDUCED ΔT BETWEEN INNER AND OUTER WALLS • REMOTE REFRIGERATOR WITH PUMPED FLUID COOLING REDUCES CHANCE OF SINGLE POINT FAILURE	• SLIGHTLY HIGHER POWER CONSUMPTION UNDER WORST CASE CONDITIONS • MORE COMPLEX HEATER CONTROL REQUIREMENTS

TRW SYSTEMS GROUP

Results of transient calculations are shown on this chart which relate the SEV gradient to the temperature difference between the inner wall and the window. The indication is that this difference must be on the order of 1°C or less to meet the requirement of .005°C uniformity and to have margin for other effects on the SEV.

EFFECT OF WINDOW TEMPERATURE LAG ON SEV GRADIENT FOR 100 SEC TRANSIENT

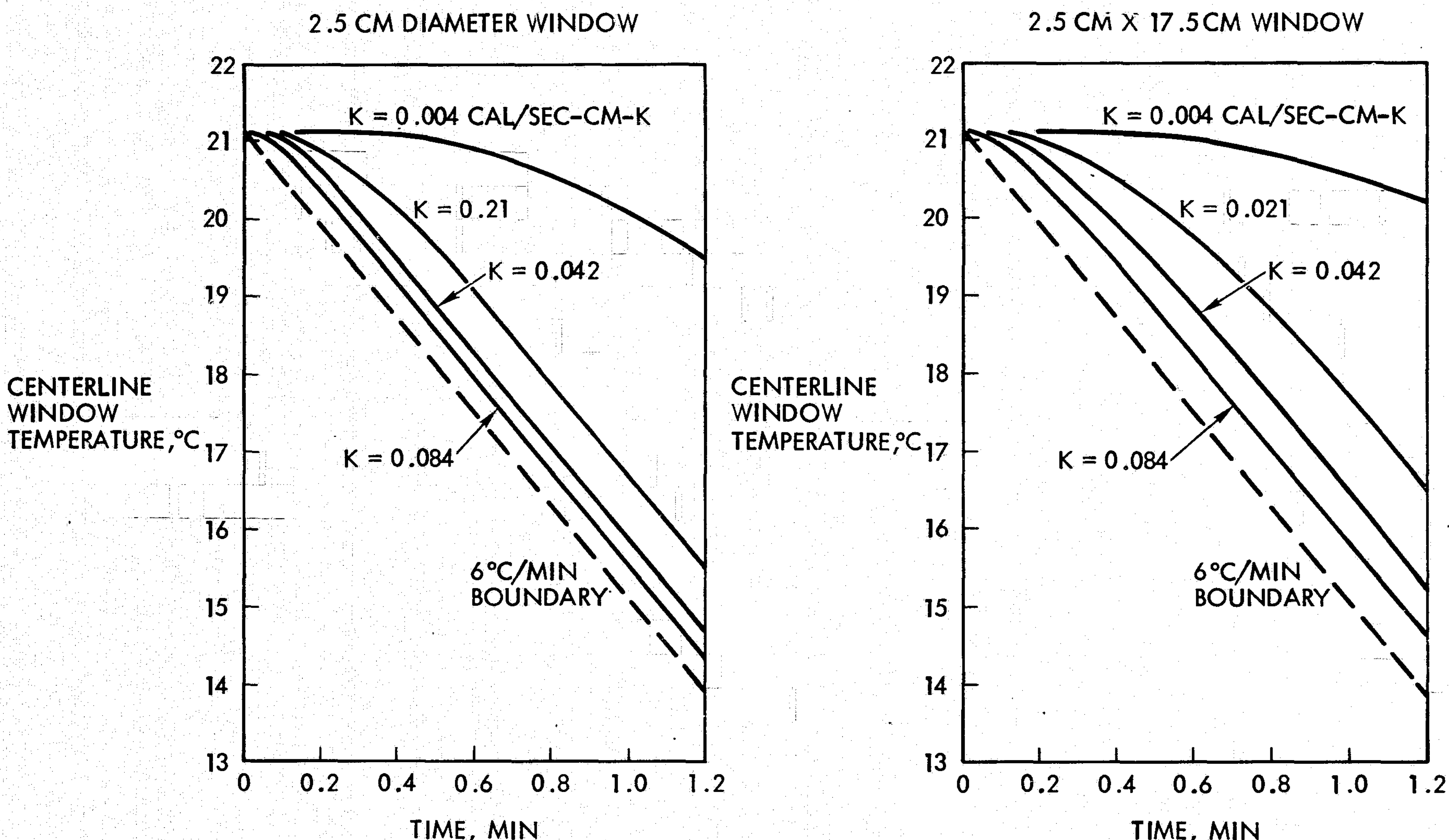




TRW SYSTEMS GROUP

Probably the largest thermal perturbation in the expansion chamber wall is caused by the windows required for illumination and photographing of the cloud. The graphs on the facing page show the temperature response of two window configurations to a boundary changing at 6°C/minute. In order to maintain the window centerline within 1°C of the boundary after 1 minute, a window conductivity of $\sim$0.07 cal/sec-cm-°K is required. Fused silica, with a thermal conductivity of $\sim$0.004 cal/sec-cm-°K is clearly unacceptable.

EXPANSION CHAMBER WINDOW COOLING



EXPANSION CHAMBER FLUID MECHANICS
CONCEPTUAL DESIGN

- FLUSHING
- STILLING
- EXPANSION
- AEROSOL LOSS CONSIDERATIONS

TRW SYSTEMS GROUP

EXPANSION CHAMBER FLUID MECHANICS REQUIREMENTS

- CHAMBER VOLUME AT LEAST 25 LITERS
- FLUSH 10 TO 14 VOLUMES PRIOR TO EXPERIMENT
- VELOCITIES IN CHAMBER NOT MORE THAN 0.03 CM/SEC PRIOR TO EXPERIMENT
- EXPANSION REQUIREMENTS 0.1 TO 1.0 MB/SEC
- EXPANSION RANGE UP TO 500 MB

TRW SYSTEMS GROUP

FLUSHING, STILLING, AND EXPANSION OF CHAMBER AIR TECHNICAL ISSUES

FLUSHING:

- APPROXIMATELY 10 VOLUMES FLUSHED THROUGH CHAMBER PURGES ALL REGIONS WITH POSSIBLE EXCEPTION OF RECIRCULATION ZONES
- LAMINAR JETS WILL LEAVE RECIRCULATION REGIONS BETWEEN JETS ESSENTIALLY UNPURGED
- TURBULENT JETS MAY BE REQUIRED TO ASSURE PURGING
- AEROSOL LOSSES DURING FLUSHING TO BE MINIMIZED

STILLING:

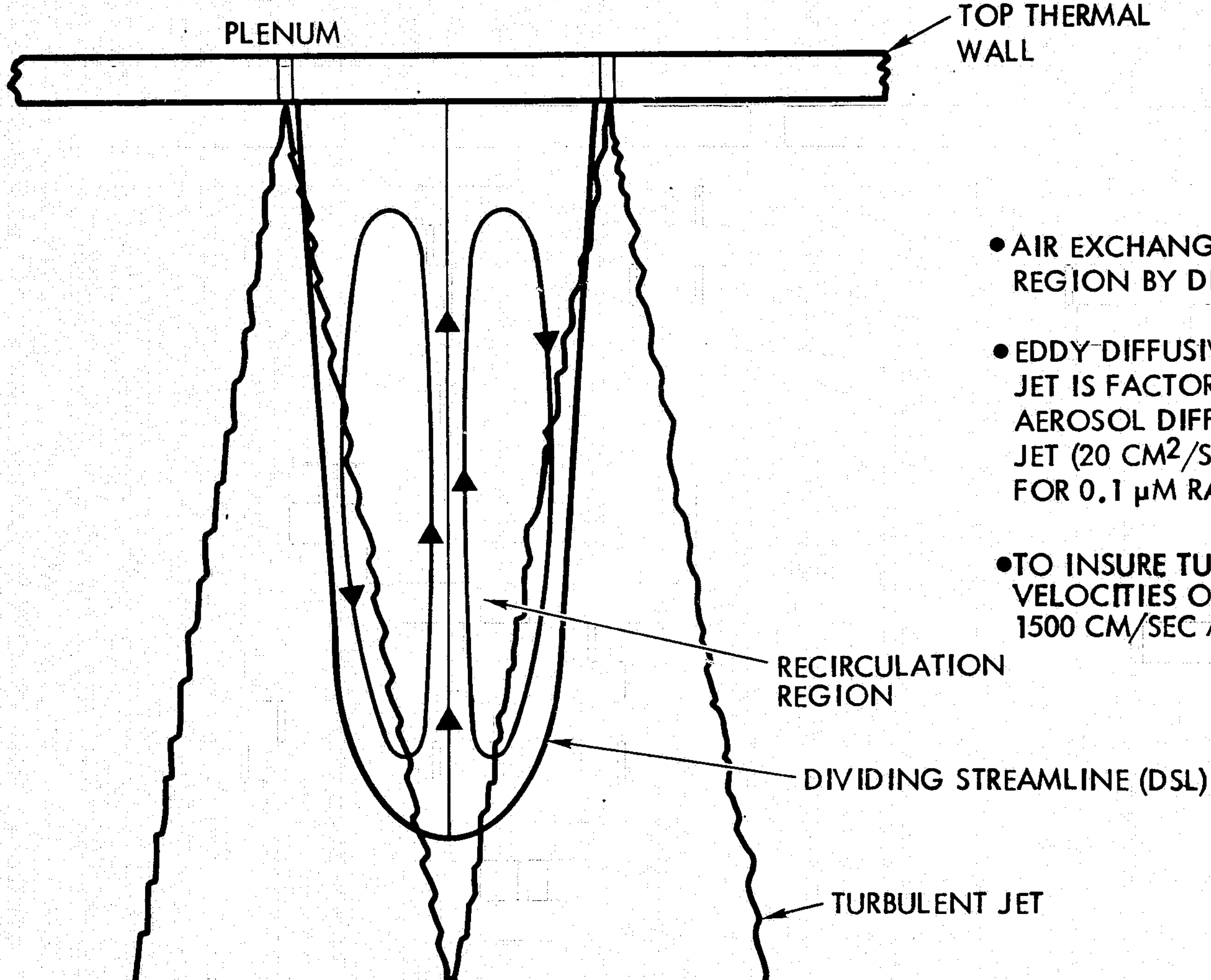
- VELOCITIES TO BE LESS THAN 0.03 cm/SEC PRIOR TO EXPANSION
- STILLING SHOULD TAKE PLACE RAPIDLY TO MINIMIZE AEROSOL LOSSES

EXPANSION:

- VELOCITIES LOW WITHIN SEV TO AVOID STREAKING OF PHOTOGRAPHS
- SIMULATE UNIFORM, SLUG FLOW EXPANSION AS CLOSELY AS POSSIBLE

Between each triplet of jets, a recirculation zone exists which does not exchange mass convectively with the jets. Concentrations of gas or aerosol initially in these volumes will be flushed only by diffusive exchange with the neighboring jets. Because of the low diffusion coefficients for the largest aerosol particles, turbulent mixing is highly desirable to minimize flushing times.

CHAMBER FLUSHING WITH TURBULENT JETS

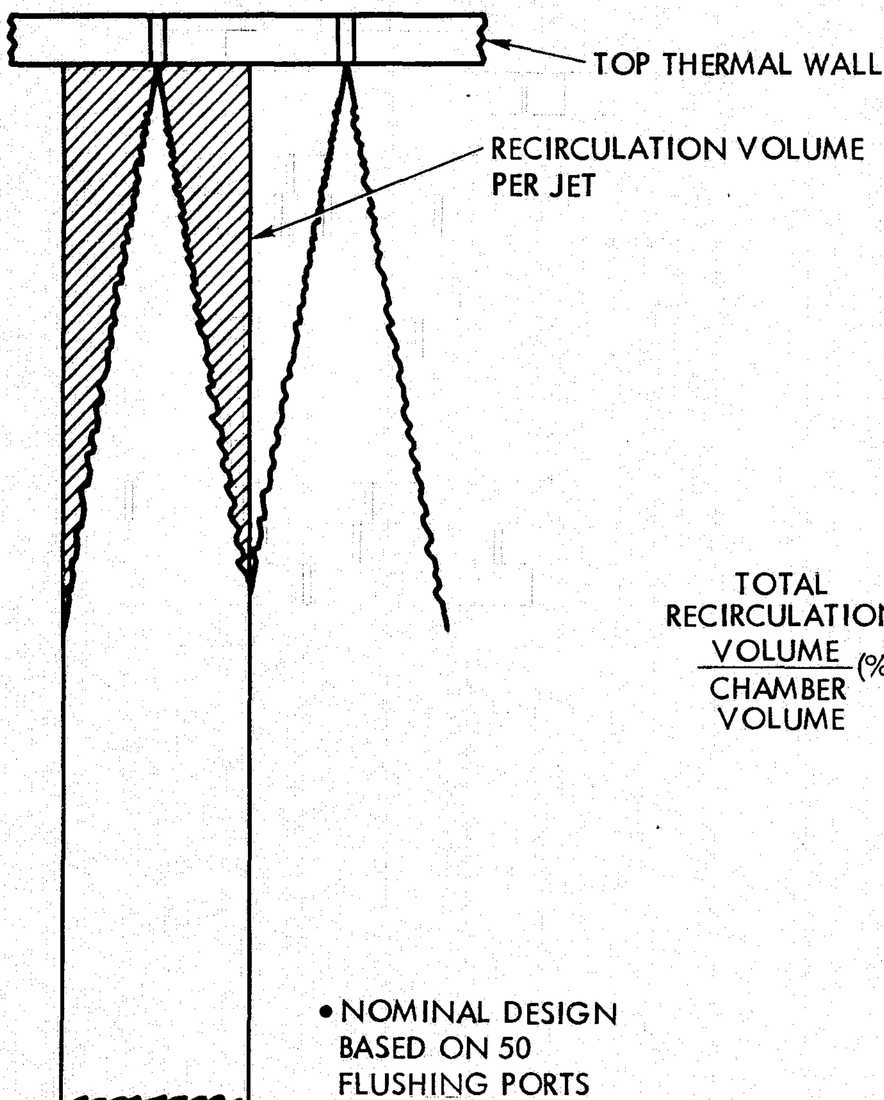


- AIR EXCHANGE IN RECIRCULATION REGION BY DIFFUSION
- EDDY DIFFUSIVITY WITH TURBULENT JET IS FACTOR OF 10^7 HIGHER THAN AEROSOL DIFFUSIVITY WITH LAMINAR JET (20 CM^2/SEC VS. 2×10^{-6} CM^2/SEC FOR 0.1 μM RADIUS PARTICLES)
- TO INSURE TURBULENT MIXING JET VELOCITIES OF APPROXIMATELY 1500 CM/SEC ARE REQUIRED

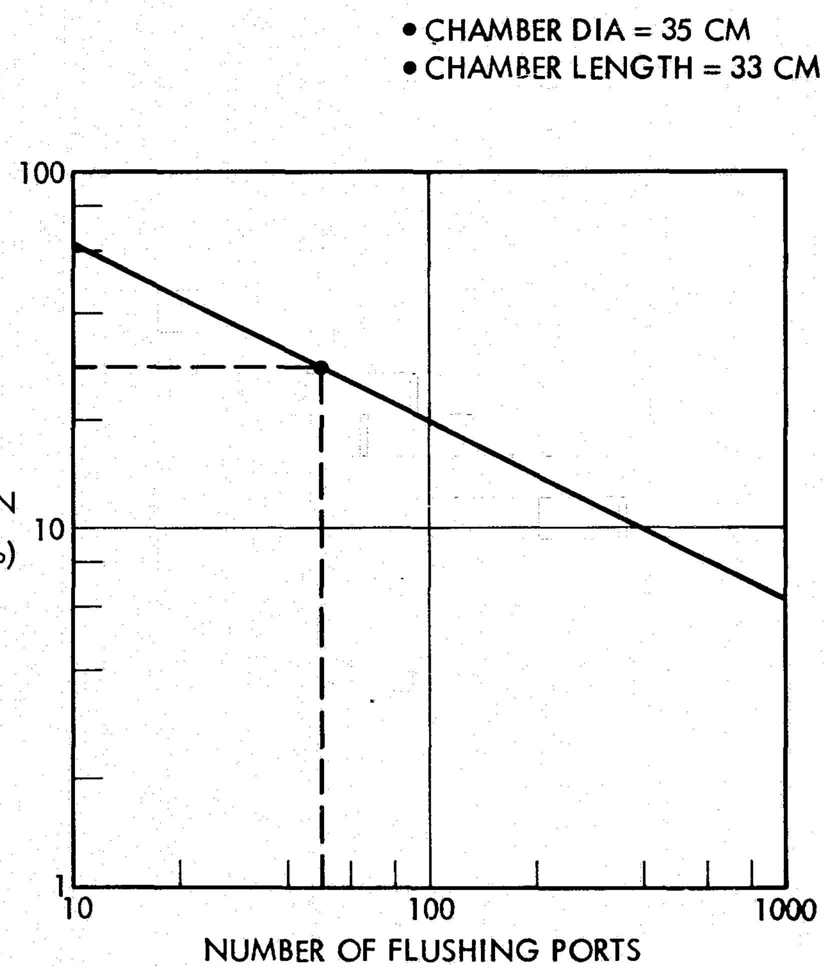
TRW SYSTEMS GROUP

Turbulent jets spread conically with about a 20° total angle. The jets are assumed to merge at a distance where the total cross sectional area of all jets is equal to the chamber cross-section. The recirculation volume per jet is the volume **within** the column which is subtended by the maximum circular diameter of the jet (i.e., at the point where the jets merge) which is external to the 20° cone.

RECIRCULATION REGION VOLUME FRACTION



• NOMINAL DESIGN BASED ON 50 FLUSHING PORTS



TRW SYSTEMS GROUP

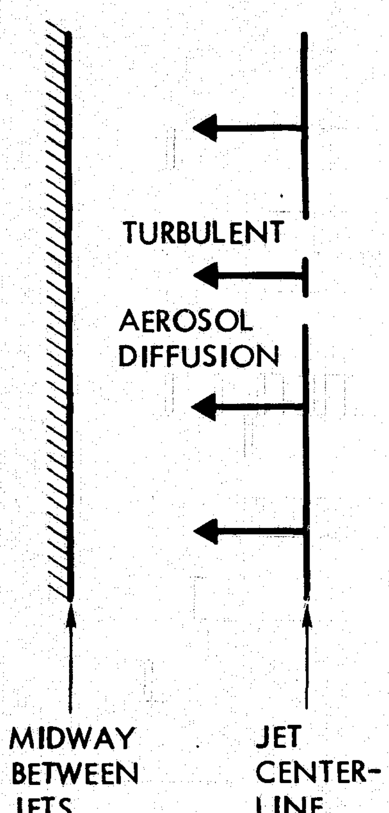
Turbulent diffusion equilibration time between jets is estimated based on a cylindrical heat conduction analogy in which aerosols (temperature) diffuse from the jet centerline, where the concentration is fixed, to the center of the recirculation region, where the concentration (temperature) gradient is zero. The diffusion coefficient over this whole region is taken to be the diffusion coefficient within the turbulent jet.

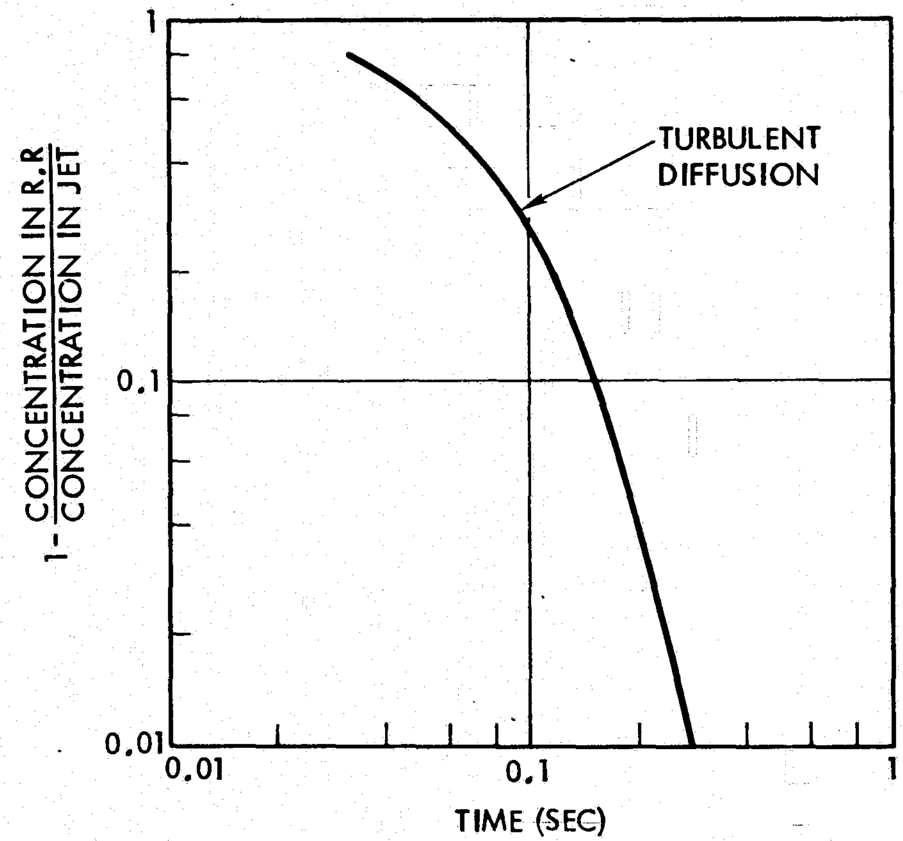
Since the recirculation volume represents about 30% of the total expansion chamber volume for our baseline design, the recirculation zones must be mixed to 3.3% at the completion of flushing to produce a 1% error in the average expansion chamber aerosol concentration.

TURBULENT DIFFUSION INTO RECIRCULATION REGION

$$\frac{\partial C_i}{\partial t} = D \frac{\partial^2 C_i}{\partial r^2}$$

- 50 FLUSHING PORTS
- CHAMBER DIA = 35 CM





- OVER 99% AIR EXCHANGE WITHIN RECIRCULATION REGIONS IN <1 SEC
- CHAMBER FLUSHING PERIOD OF ≈ 500 SECONDS ASSURES UNIFORM FLUSHING

STILLING

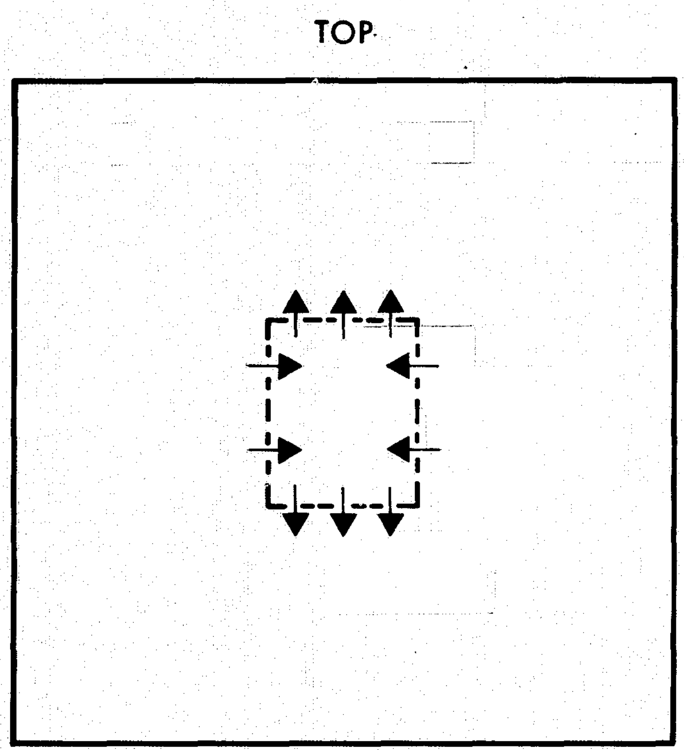
- VORTICES ON THE ORDER OF THE CHAMBER RADIUS ARE NOT ANTICIPATED FOR THE PRESENT FLUSHING CONCEPT.

- STILLING TIME FOR SMALL SCALE TURBULENT MOTIONS MAY BE SHORT COMPARED WITH PREVIOUS ESTIMATES OF STILLING TIME (~ 15 MINUTES).

The droplet motion induced within the SEV by the expansion will be slow enough that the particles will be "frozen" by the camera flash and streaking will not degrade the results of the experiment.

Boundary layers building up on side walls during the course of an expansion may force fluid and aerosols into the SEV from the neighboring region. This effect is expected to have no significant effect on the results of the experiment.

EXPANSION



- VELOCITY AT SEV TOP AND BOTTOM BOUNDARIES ~ 0.1 MM/SEC
- FLASH TIME 45MSEC
- PARTICLE MOVEMENT DURING FLASH ~4.5 X 10^{-6} MM ($\ll$ SMALLER THAN FILM RESOLUTION)
- POSSIBLE RADIAL FLOW INTO SEV DURING EXPANSION IF POISEUILLE LIKE FLOW DEVELOPS – FLOW WOULD BE DRAWN FROM REGION < 0.6 CM BEYOND SEV

TRW SYSTEMS GROUP

Aerosol losses during stilling are currently being evaluated. All other aerosol loss mechanisms within the expansion chamber are expected to be negligible.

AEROSOL LOSSES

FLUSHING:

- DIFFUSION LOSSES IN FLUSHING PORTS NEGLIGIBLE
- DIFFUSION LOSSES IN EXPANSION CHAMBER MAY BE SIGNIFICANT DUE TO TURBULENCE -- BUT AEROSOLS ARE BEING CONTINUOUSLY SUPPLIED

STILLING:

- DIFFUSION LOSSES DURING STILLING DEPEND ON DETAILS OF STILLING PROCESS WHICH ARE STILL UNDER INVESTIGATION

STILL AIR:

- DIFFUSION LOSSES CONFINED DISTANCES OF ~ 1.5 CM FROM CHAMBER WALLS FOR 0.01 μM RADIUS PARTICLES (1000 SECONDS)
- COAGULATION LOSSES LESS THAN 0.1%

TRW SYSTEMS GROUP

SCIENTIFIC SUBSYSTEMS

PRECEDING PAGE BLANK NOT FILMED

OPTICAL AND IMAGING SUBSYSTEM

TRW SYSTEMS GROUP

OPTICAL AND IMAGING SUBSYSTEM

TYPICAL ANALYSIS AND TRADES

APPARATUS	SCIENTIFIC REQUIREMENTS			ANALYTICAL RESULTS					ELECTRICAL NEEDS			
						CAMERA LENS					AVERAGE ELECT POWER	
	PARTICLE TYPE	MINIMUM RECORDED SIZE (RADIUS) MICRONS	FRAME RATE	FORMAT W (WIDTH) CM	SIZE H (HEIGHT) CM	Δq (FOCAL DEPTH) CM	FOCAL LENGTH MM	DISTANCE FROM CHAMB. CENTER CM	FLASH DURATION MICRO-SECONDS	ELECTRICAL ENERGY PER FLASH JOULES	REACTIVE CHARGING WATTS	RESISTIVE CHARGING
EXPANSION CHAMBER	WATER DROPLETS	2 μ 2 μ 2 μ	0.1/SEC 1/SEC 3/SEC	7	10	1.5	50	20	45 45 45	26 26 26	2.6 26 78	5 50 156
	ICE XTALS	10 μ	0.1/SEC 1/SEC 10/SEC	19	27	2.0	21	20	12 12 12	7 7 7	0.7 7 70	1.5 14 140
SDL	WATER DROPLETS	2 μ	1/SEC	1.0	0.42	1.0	62	8	12	6	6	12

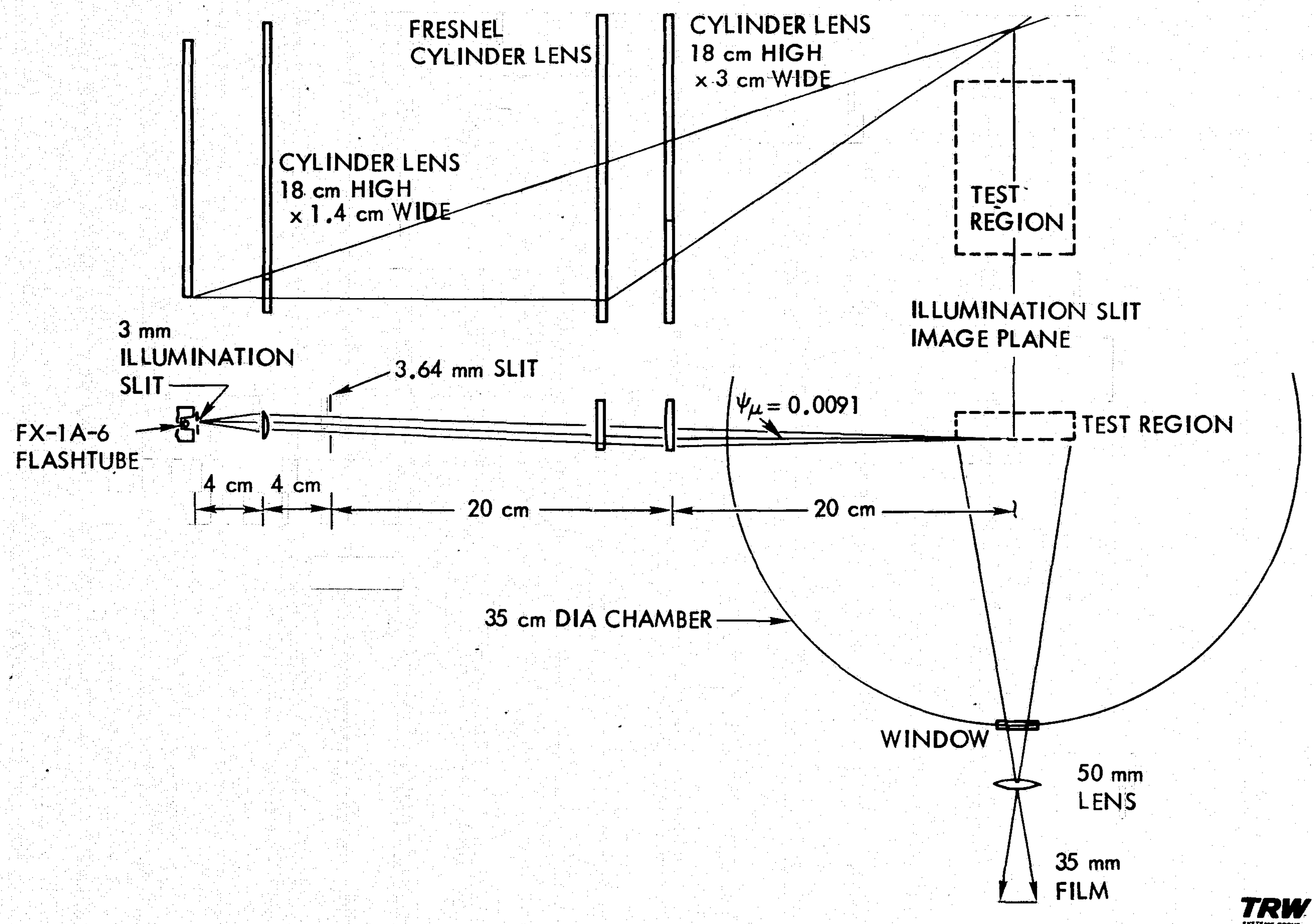
TRW SYSTEMS GROUP

The optical subsystem for the Expansion Chamber is shown in the accompanying drawing. Particles inside the chamber are photographed by their own scattering of light from a linear xenon flashlamp.

The 3 x 150 mm illumination slit formed by the aperture in the flashlamp housing is imaged in the center of the test region. In the vertical direction the magnification is unity; in the horizontal direction the magnification is five times. The 3.64 mm slit restricts the half-angle of the illumination fans to 0.0091 radians and thereby limits the thickness error in the test region to about 2%. The total radiant flux into the test chamber is about 0.2 watts. Half of this power is not effective in exposing the film and can be eliminated by means of a spectral filter, not shown in the drawing.

The test region is reduced three times before falling on the 35 mm film frame for recording. The f/20 camera lens has a depth of field of 1.5 cm which matches the thickness of the test region.

EXPANSION CHAMBER OPTICS SCHEMATIC



OPTICAL AND IMAGING SUBSYSTEM

AUTORADIOGRAPHIC IMAGE INTENSIFICATION

- PROCESS DEVELOPED AT MSFC
- CAN PROVIDE UP TO A FACTOR OF 32 INCREASE IN EFFECTIVE FILM SPEED
- THIS FACTOR OF 32 COULD BE ALLOCATED TO ACHIEVE SOME COMBINATION OF THE FOLLOWING:
  - REDUCTION IN ELECTRICAL POWER
  - SIMPLIFICATION OF THE OPTICS
  - MORE PRECISE SEV DEFINITION
  - DETECTION OF SMALLER DROPLETS

TRW SYSTEMS GROUP

AEROSOL GENERATOR SUBSYSTEM

The preliminary design of the Aerosol Generator Subsystem is almost complete. The status of the five major equipment items is summarized here.

AEROSOL GENERATOR SUBSYSTEM
STATUS OF MAJOR EQUIPMENT ITEMS

• NaCl GENERATOR	DESIGN BASED ON EXISTING LABORATORY GENERATOR
• H_2SO_4 GENERATOR	DESIGN DERIVED FROM LABORATORY TECHNIQUES
• AEROSOL NEUTRALIZER	PURCHASE COMMERCIAL ITEM
• STORAGE BAG MANIFOLD	DESIGN BASED ON TRW CONCEPT
• ELECTROSTATIC CLASSIFIER	PURCHASE COMMERCIAL ITEM AND MODIFY

TRW SYSTEMS GROUP

The Aerosol Generator Subsystem preliminary design provides the listed performance characteristics for the initial ACPL as required by the NASA Level I Specification (August 12, 1976). Specific provisions have also been included to accommodate the listed growth potential.

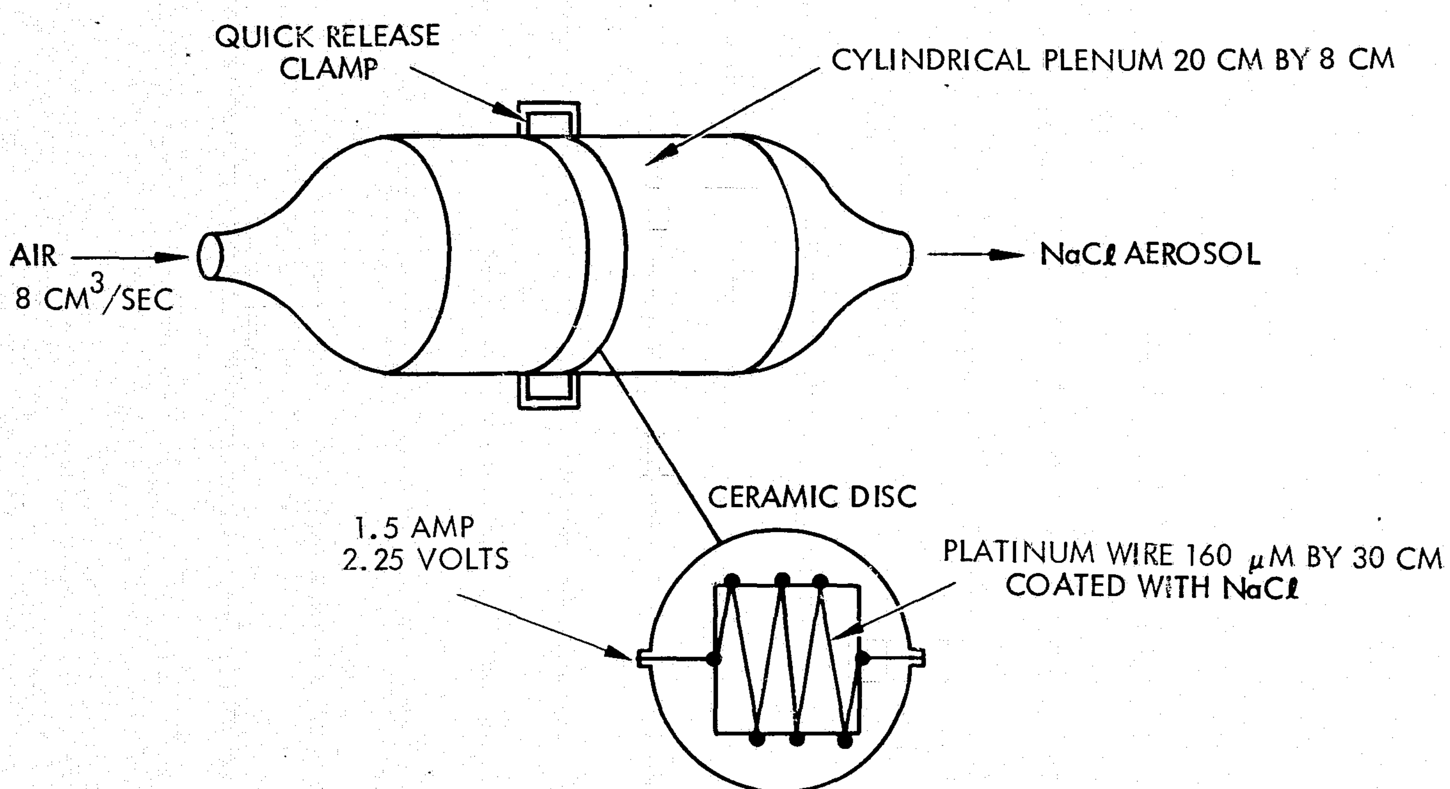
AEROSOL GENERATOR SUBSYSTEM PERFORMANCE SPECIFICATIONS

- INITIAL ACPL
  - GENERATES CHEMICALLY PURE NaCl AND H_2SO_4 AEROSOLS
  - CUMULATIVE NUMBER OF ACTIVATED PARTICLES INCREASES WITHOUT INFLECTION POINTS WITH INCREASING S_C OVER THE RANGE 0.1% TO 3%
  - CONCENTRATION OF PARTICLES AFTER FINAL DILUTION ADJUSTABLE FROM 100 TO 1000 CM^{-3} THAT ACTIVATE OVER THE RANGE $0.05\% < S_C < 3\%$
  - CONCENTRATION OF PARTICLES AFTER FINAL DILUTION LESS THAN 0.1 CM^{-3} WITH RADIUS GREATER THAN 0.1 μM
  - AEROSOL PARTICLES ELECTRICALLY NEUTRAL
  - MONODISPERSE AEROSOLS OF BOTH MATERIALS CAN BE OBTAINED
  - AEROSOLS CAN BE INTRODUCED BOTH UPSTREAM AND DOWNSTREAM OF SATURATOR
- GROWTH POTENTIAL
  - DIFFUSION BATTERY CAN BE INSTALLED TO REMOVE PARTICLES LESS THAN 0.01 μM RADIUS
  - A THIRD AEROSOL GENERATOR CAN BE INSTALLED

TRW SYSTEMS GROUP

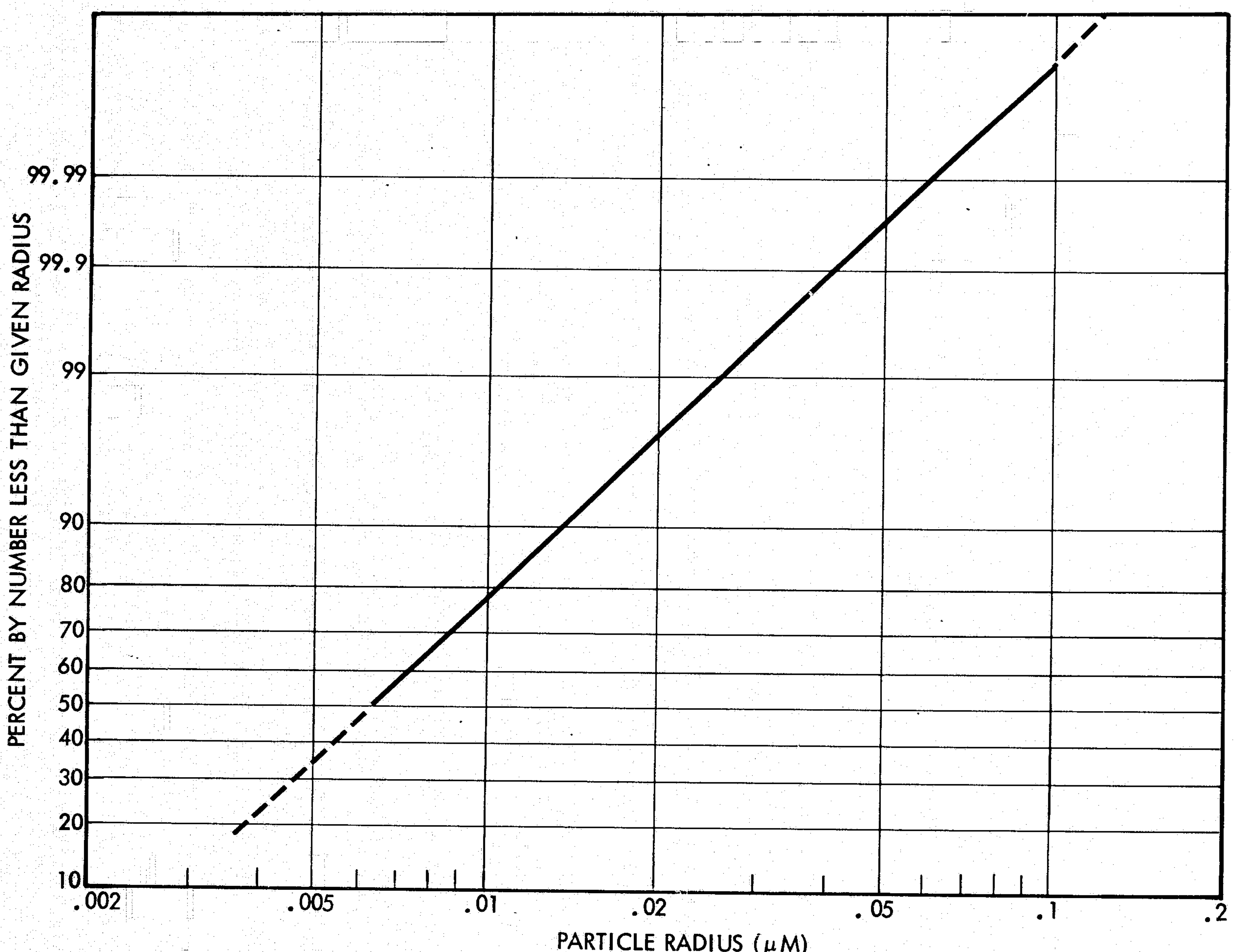
The generator used to produce the NACL aerosols was described at Concept Review. Its functional characteristics are summarized here.

EVAPORATION-CONDENSATION AEROSOL GENERATOR



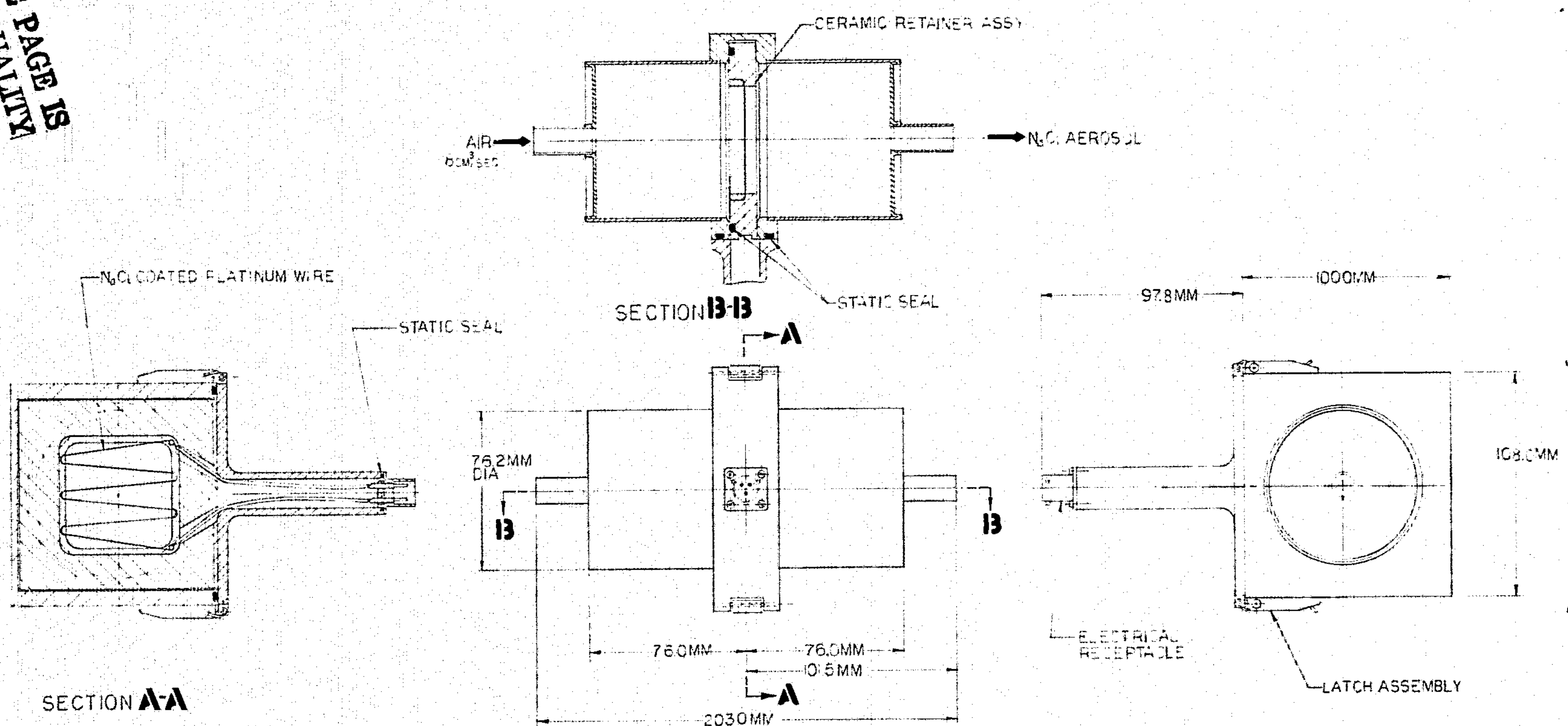
The NACL generator design is based on published laboratory work. The aerosol produced by the existing generator has been characterized in the laboratory and a typical particle size distribution is shown here.

NACL AEROSOL GENERATOR SIZE DISTRIBUTION



The details of the NACL aerosol generator preliminary design are shown here.

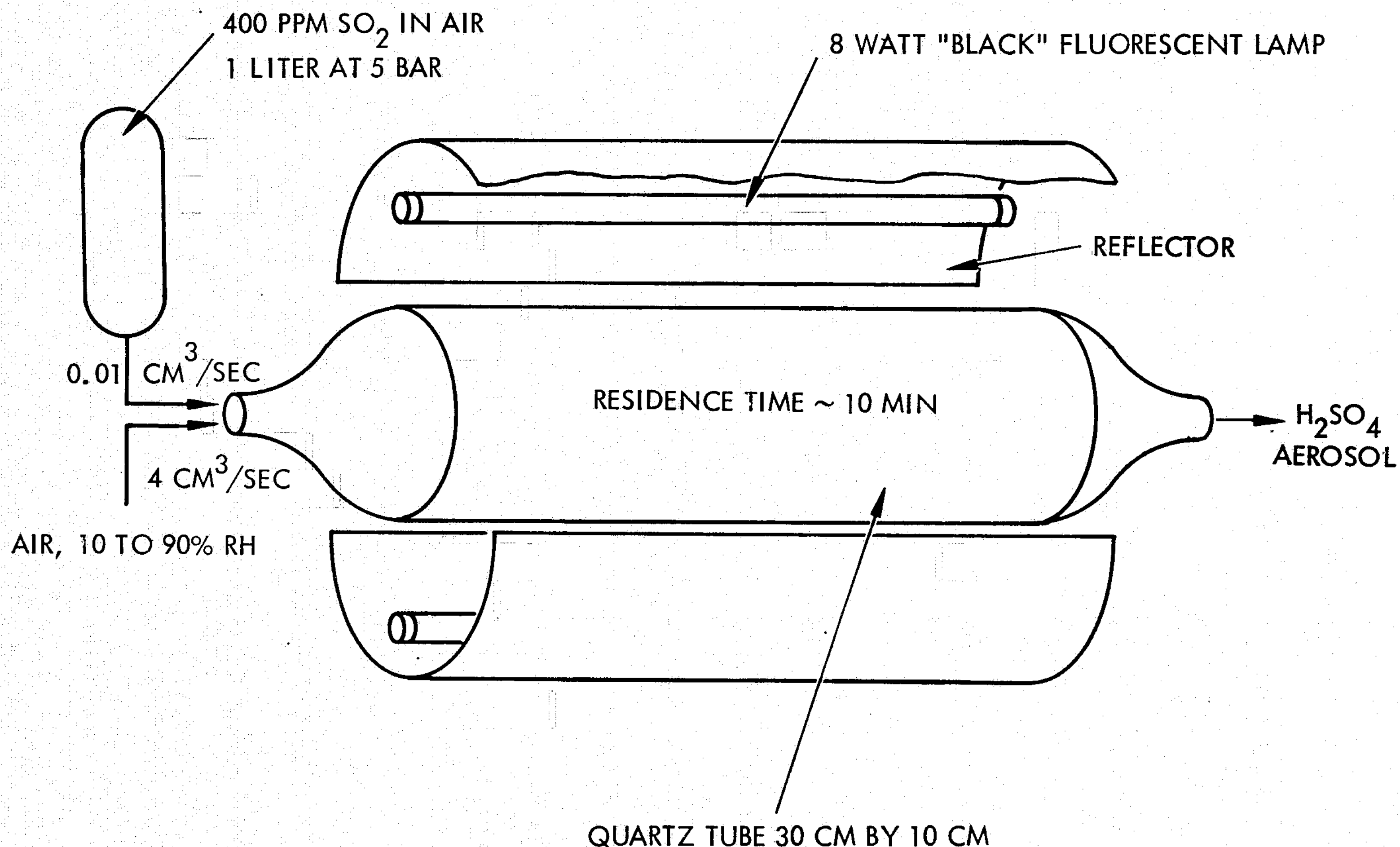
NaCl AEROSOL GENERATOR PRELIMINARY DESIGN



EVAPORATION-CONDENSATION AEROSOL GENERATOR

The generator used to produce the H_2SO_4 aerosols was described at Concept Review. Its functional characteristics are summarized here.

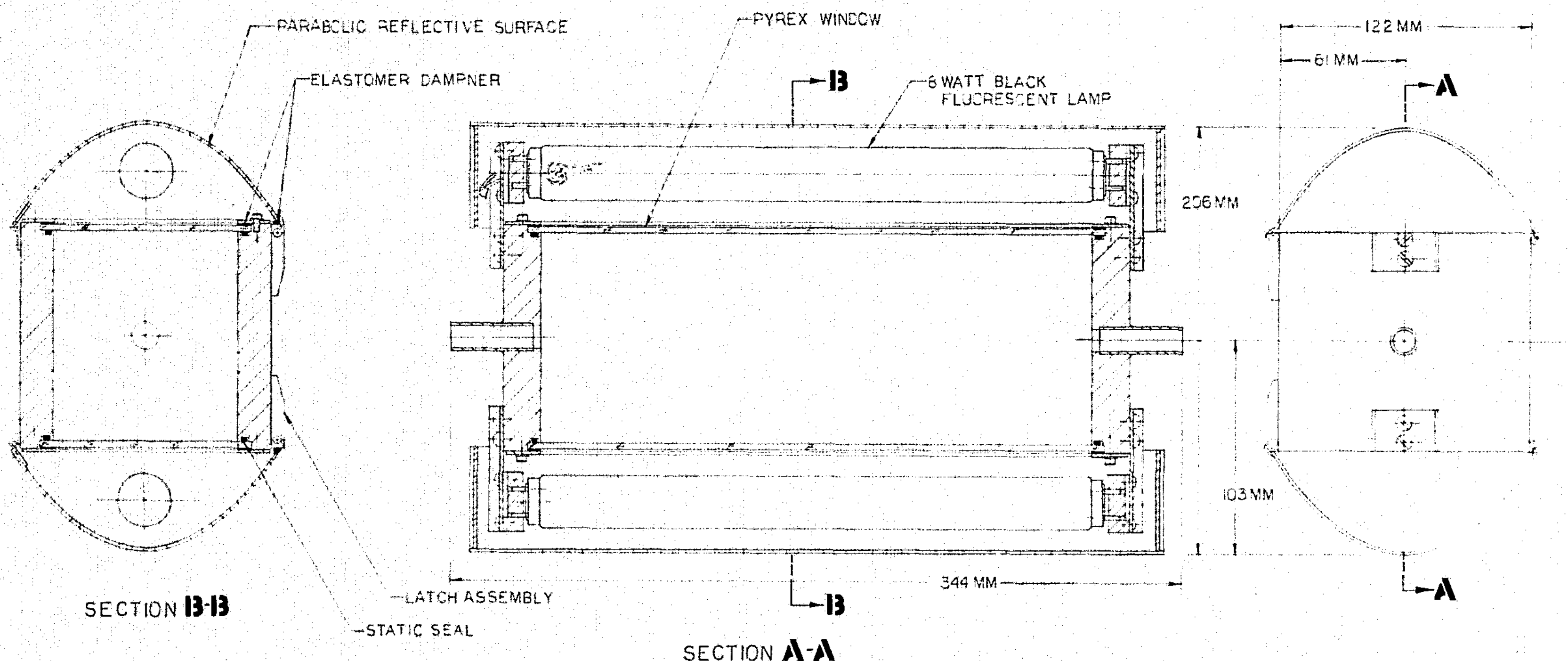
PHOTOCHEMICAL AEROSOL GENERATOR



TRW
SYSTEMS GROUP

The details of the H_2SO_4 generator preliminary design are shown here.

H_2SO_4 AEROSOL GENERATOR PRELIMINARY DESIGN

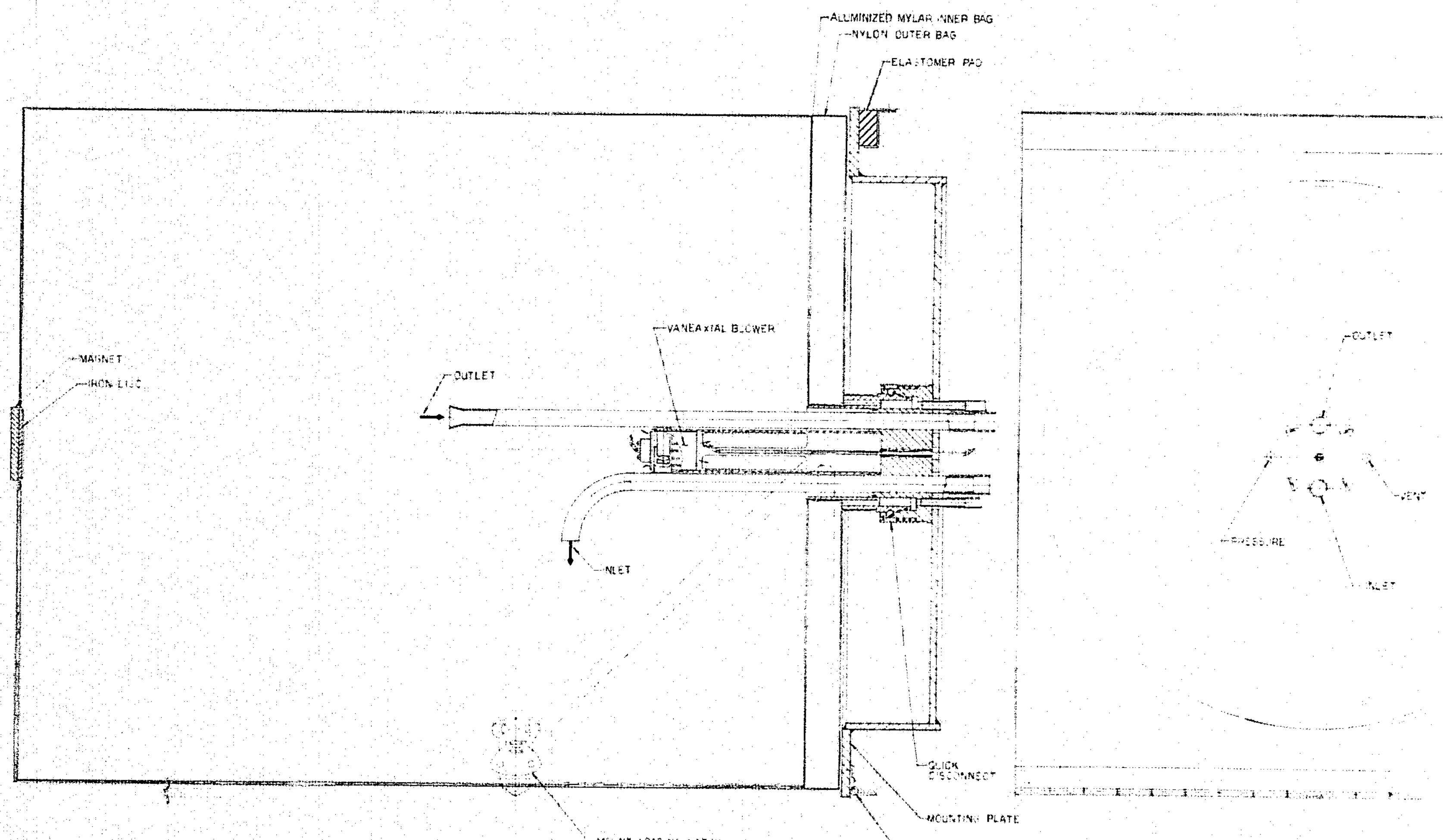


PHOTOCHEMICAL AEROSOL GENERATOR

TRW SYSTEMS GROUP

The details of the aerosol storage bag and manifold are shown here.

AEROSOL STORAGE BAG PRELIMINARY DESIGN



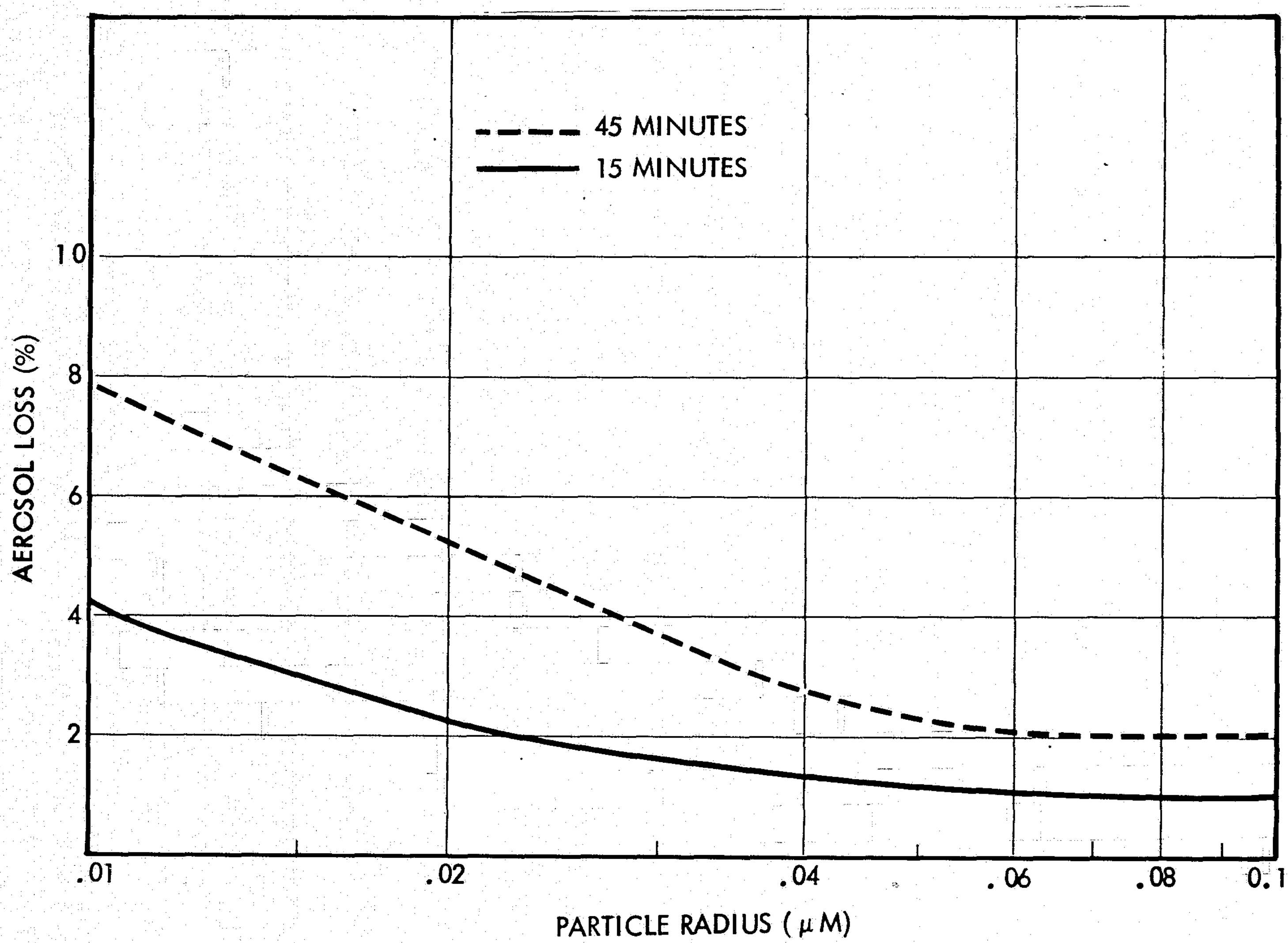
NOTES: UNLESS OTHERWISE SPECIFIED

STORAGE BAG ASSEMBLY

TRW
SYSTEMS GROUP

The theoretically predicted decay of monodisperse aerosols in the storage bag is shown as a function of particle radius for two time intervals.

ZERO-G DECAY OF MONODISPERSE AEROSOLS BY COAGULATION AND DIFFUSION



TRW SYSTEMS GROUP

The theoretically predicted decay of polydisperse aerosols in the storage bag is summarized here.

ZERO-G DECAY OF POLYDISPERSE AEROSOLS BY COAGULATION AND DIFFUSION

- FOR $n = CS_c^K$ DISTRIBUTION

AEROSOL LOSS (PERCENT)

K	15 MIN	45 MIN
0.5	2.8	6.1
1.0	2.9	5.7
2.0	3.3	6.3

TRW SYSTEMS GROUP

PRECEDING PAGE BLANK NOT FILMED

AEROSOL COUNTER SUBSYSTEM

TRW SYSTEMS GROUP

Further consideration of the requirement to collect an aerosol sample for electron microscope analysis has led to a reevaluation of the approach discussed at Concept Review.

AEROSOL COUNTER SUBSYSTEM
LOCATION OF AEROSOL SAMPLER

- COLLECT PARTICLES FOR ELECTRON MICROSCOPE ANALYSIS
- PRIMARY RANGE OF 0.01 TO 0.1 μM RADIUS PARTICLES REQUIRES MAGNIFICATION OF THE ORDER OF 50,000
- RESULTING FIELD-OF-VIEW ON THE ORDER OF 2 μM BY 2 μM OR 4×10^{-8} CM^2
- OBSERVING ONE PARTICLE PER FOV REQUIRES 25×10^6 PARTICLES PER CM

TRW SYSTEMS GROUP

SUPPORT SUBSYSTEMS

PRECEDING PAGE BLANK NOT FILMED

TRW
SYSTEMS GROUP

PRECEDING PAGE BLANK NOT FILMED

FLUID SUBSYSTEM

TRW
SYSTEMS GROUP

The function of the Fluid Subsystem is to provide air and aerosol circulation throughout the ACPL. The design elements which must be considered include flow, pressure and humidity measurement and control. In addition, special care must be exercised to control aerosol diffusion losses in critical portions of the system.

FLUID SUBSYSTEM

FUNCTION:

AIR/AEROSOL CIRCULATION THROUGHOUT ACPL

FLOW MEASUREMENT AND CONTROL

- DISCRETE OR CONTINUOUS ADJUSTMENTS WHERE NECESSARY TO ACCOMMODATE EXPERIMENTS

PRESSURE MEASUREMENT AND CONTROL

- OPERATION NEAR S/L AMBIENT
- ESSENTIALLY CONSTANT PRESSURE OPERATION EXCEPT IN EXPERIMENTAL CHAMBERS

HUMIDITY MEASUREMENT AND CONTROL

- SATURATOR
- LOCAL DRYING
- AVOID CONDENSATION DOWNSTREAM OF SATURATOR

AEROSOL CONTROL

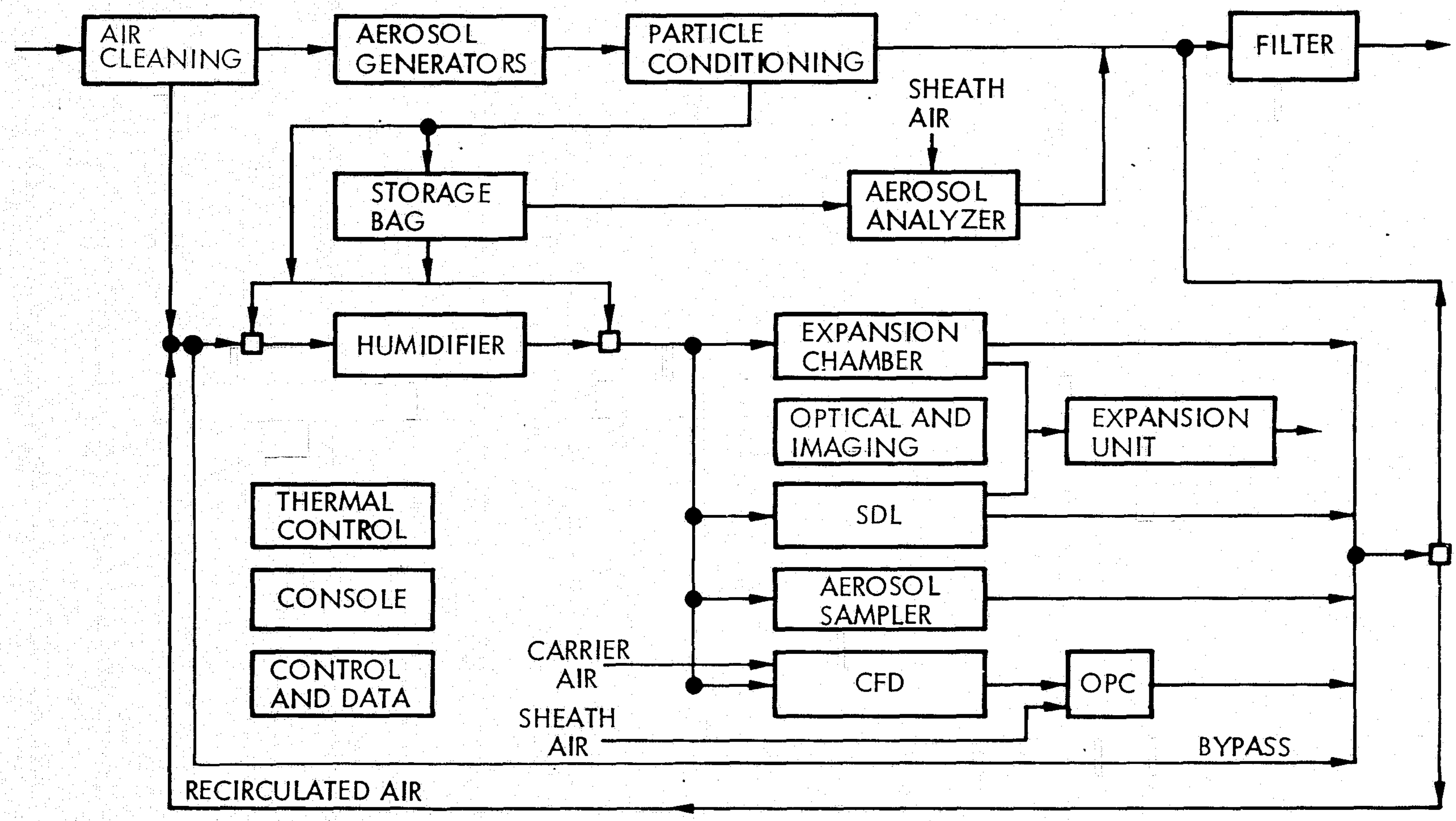
- DIFFUSION LOSSES

TRW
SYSTEMS GROUP

A simplified block diagram of the Fluid Subsystem shows that there are two main branches. A constant flow, high humidity recirculation loop which services the experimental chambers minimizes the thermal and evaporative load on the saturator. The second branch is an intermittent flow, open loop which services the aerosol generation, conditioning and measurement equipment. Intermittent flow for this branch minimizes pump power since the major flow requirement (sheath flow for the EAA) has a very low duty cycle.

An additional feature is a significant bleed to cabin from the recirculation loop in place of dessicants to passively control its humidity. It has been established that cabin ambient pressure is sufficiently stable to permit such coupling.

FLUID SUBSYSTEM BLOCK DIAGRAM



- TWO MAIN BRANCHES
- CONSTANT FLOW RECIRCULATION LOOP MINIMIZES LOAD ON SATURATOR
- INTERMITTENT FLOW OPEN LOOP MINIMIZES PUMP POWER
- USE OF CABIN BLEED FOR HUMIDITY CONTROL MINIMIZES DESSICANT REQUIREMENTS

TRW

The table on the facing page summarizes the performance of the Fluid Subsystem design in relation to the Level I Specification requirements. The Saturator will be dealt with separately. All of the stated requirements are met or exceeded by the recommended system.

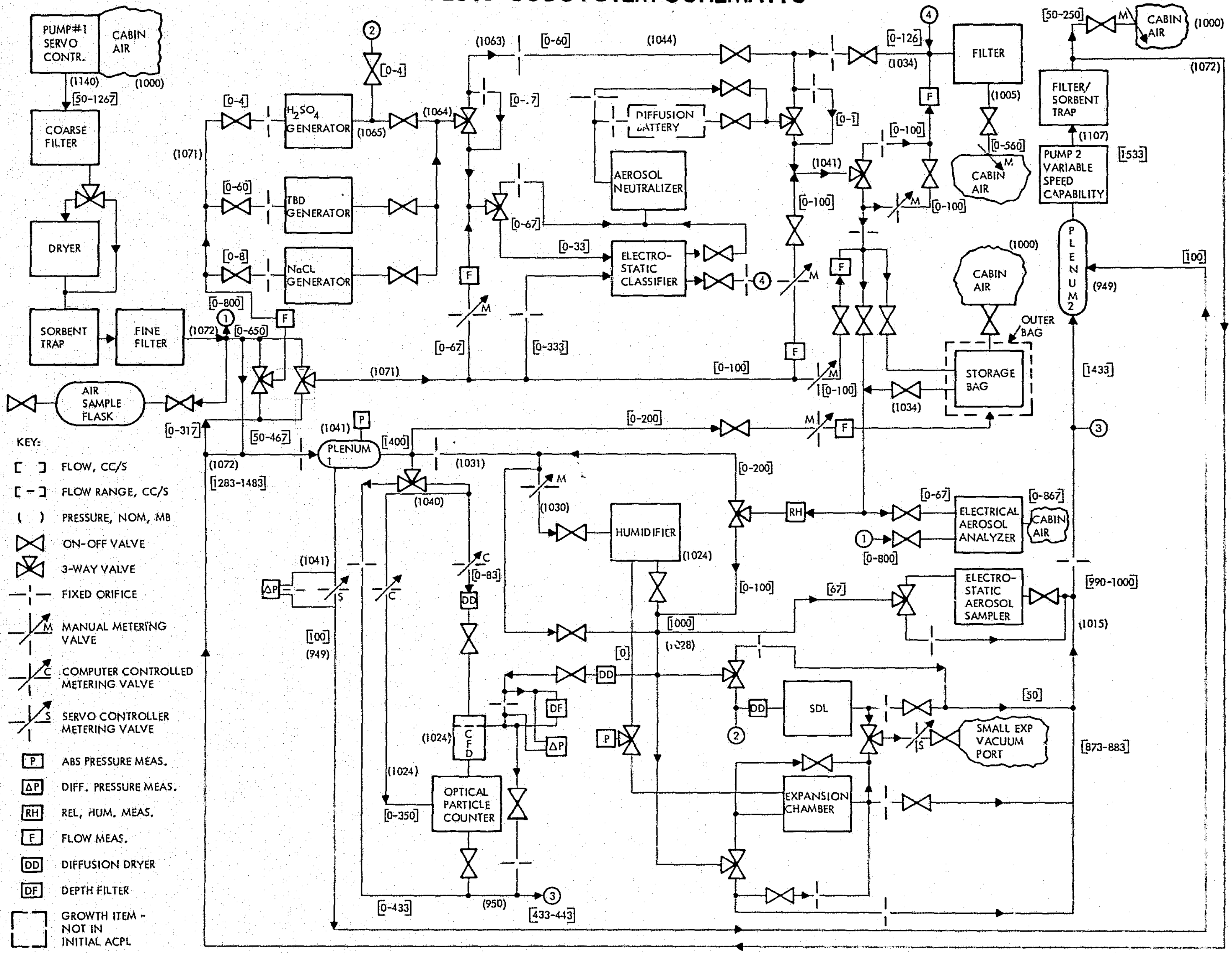
FLUID SUBSYSTEM
REQUIREMENTS AND PERFORMANCE (EXCLUDING SATURATOR)

REQUIREMENT	PERFORMANCE
• SATURATOR FLOW RATE 400-1200 CM^3/SEC 10 EXP. CH. VOLUME FLUSH IN 1000 SEC.	- FLOW RATE 900-1000 CM^3/SEC FLUSH TIME ~400 SEC
• REFERENCE POINT PRESSURE	
ABSOLUTE ACCURACY: ± 1.0 mb	- ABSOLUTE ACCURACY ± 0.5 mb
RELATIVE ACCURACY: ±0.1 mb	- RELATIVE ACCURACY ± 0.1 mb
STABILITY: ± 0.5 mb	- STABILITY (ANALOG SIMULATION) ± 0.1 mb
• NO CONDENSATION DOWNSTREAM OF SATURATOR	- BELOW AMBIENT DEW POINTS, CONTROL OF PRESSURE DROPS ASSURES MEETING REQUIREMENT
• EXPANSION CHAMBER - SATURATOR ΔP MEASURED WITH RESOLUTION OF ± 0.1 mb STEADY STATE AND + 0.5 mb DURING EXPANSIONS AT 0.1 - 1.0 mb/SEC	- NOMINAL RESOLUTION OF TRANSDUCER IS ± 0.01 mb RELATIVE ACCURACY IS ± 0.1 mb ΔP RESOLVED TO ± 0.1 mb
• EXPANSION CHAMBER PRESSURE MATCHES PRESCRIBED P, t CURVE TO ± 0.5 mb	- OFF THE SHELF, INTEGRATED PRESSURE CONTROL SYSTEM PROVIDES MEASUREMENT AND CONTROL TO ±0.5 mb
• 500 mb EXPANSION FROM 0.8 - 1.2 TIMES S/L AMBIENT PERFORMED TO ± 0.5 mb	- SYSTEM ACCURACY AND CONTROL <±0.05% OF READING OVER 100 - 1000 mb RANGE
• EXPANSION RATE 0.1 - 1.0 mb/SEC	- SYSTEM PROVIDES EXPANSION RATE OF 4 X 10^{-5} TO 3.11 mb/SEC FOR P ≥500 mb
• CFD SAMPLE FLOW KNOWN TO ±1%	- ΔP MEASURED ACROSS CALIBRATED ORIFICE WITH ACCURACY OF ± 0.08% IN RANGE OF INTEREST

TRW SYSTEMS GROUP

The fluid subsystem schematic is shown on the facing page. The schematic shows the major components as well as pressure levels and flow rates throughout. Specific features of the subsystem will be described in the following discussion.

FLUID SUBSYSTEM SCHEMATIC



The facing page describes the Fluid Subsystem features pertaining to pressure and flow control.

Pressure and flow control in the ACPL is achieved with a minimum of active control elements.

Basically, the system operates as a pressure divider providing constant flow through fixed resistances between two pressure controlled plenums.

FLUID SUBSYSTEM
PRESSURE AND FLOW CONTROL

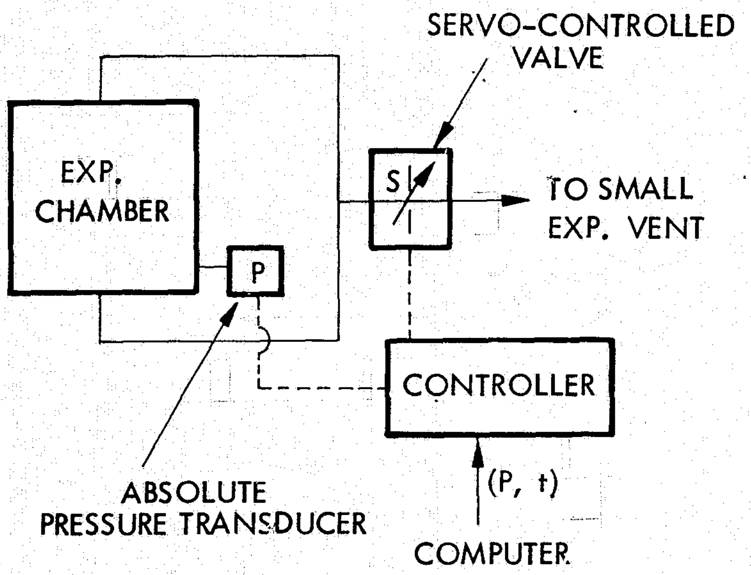
- ACTIVE CONTROL
  - ABSOLUTE PRESSURE OF SYSTEM MAINTAINED THROUGH SERVO-CONTROL OF INLET PUMP SPEED
  - DIFFERENTIAL PRESSURE BETWEEN PLENUMS MAINTAINED WITH SERVO-CONTROL OF BYPASS VALVE. PROVIDES CONSTANT FLOW TO EXPERIMENTAL CHAMBERS
  - EXPANSION OF SDL (AITKEN COUNTER) AND EXPANSION CHAMBER WITH SERVO-CONTROLLED VALVE TO SMALL EXPERIMENT VENT
- COMPUTER ADJUSTED PASSIVE CONTROL
  - INCREMENTAL VALVES TO ADJUST CFD CARRIER AND OPC SHEATH FLOW
- MANUALLY ADJUSTED PASSIVE CONTROL
  - METERING VALVES TO CONTROL DILUTION, AEROSOL AND BLEED FLOWS
  - RECIRCULATION PUMP SPEED CONTROLS NOMINAL FLOW RATE IN LOOP
- FIXED PASSIVE CONTROL
  - LOOP BALANCED WITH PRESSURE DROPS ACROSS FIXED ORIFICES
  - EQUIVALENT RESISTANCE BYPASSES FOR EACH EXPERIMENTAL CHAMBER PROVIDES NEARLY CONSTANT RECIRCULATION LOOP RESISTANCE AND MINIMIZES DYNAMIC RANGE OF SERVO-CONTROLLED BYPASS
  - SYSTEM OPERATES AS A PRESSURE DIVIDER PROVIDING PRESSURE AND FLOW REGULATION WITH MINIMAL ACTIVE CONTROL
  - NO ACTIVE CONTROL ELEMENTS OR SENSORS IN AEROSOL LINES PREVENTS DRIFT DUE TO CONTAMINATION
  - ACTIVE CONTROL BASED ON PRESSURE MEASUREMENT. PROVIDES GREATER ACCURACY THAN FLOW MEASUREMENT

TRW SYSTEMS GROUP

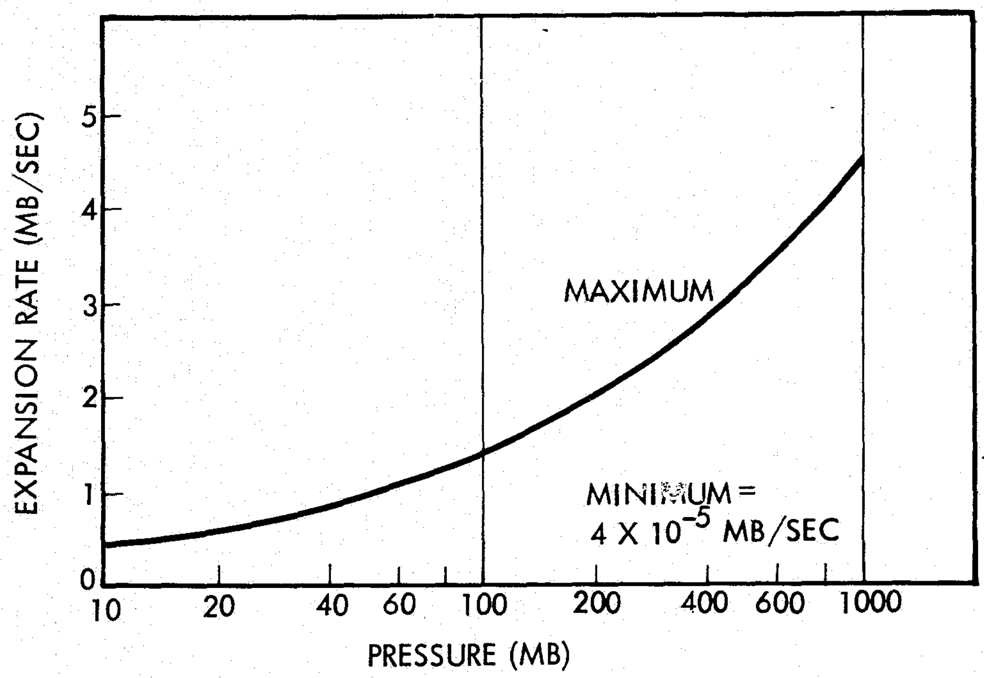
Controlled pressure reduction in the Expansion Chamber will be through a servo-controlled valve to space vacuum through the small experiment vent.

The pressure transducer, controller and valve selected are commercially available and meet or exceed all requirements on measurement, control and rate of expansion for the initial ACPL. In fact, the system has sufficient dynamic range to operate down to 10 mb. Below 60 mb, however, the maximum expansion rate will be lower than 1 mb/sec.

EXPANSION MECHANISM FOR EXPANSION CHAMBER



DYNAMIC RANGE OF SYSTEM



- o SYSTEM EXCEEDS INITIAL REQUIREMENTS OF 0.1 - 1.0 MB/SEC FOR 500 MB EXPANSION FROM 1013 MB
- o SYSTEM HAS SUFFICIENT DYNAMIC RANGE TO OPERATE DOWN TO 10 MB
- o COMMERCIALLY AVAILABLE HARDWARE

TRW
SYSTEMS GROUP

With regard to aerosol flow control, dilution and storage, the Fluid Subsystem provides three operating modes to accommodate advances in the state-of-the-art in particle generators.

A storage bag is included for use with present state-of-the-art, unstable generators. However, provision is made for operation with near-stable and stable generators when they are developed.

FLUID SUBSYSTEM
AEROSOL FLOW CONTROL, DILUTION AND STORAGE

THREE OPERATING MODES ARE PROVIDED

(1) HIGHLY UNSTABLE AEROSOL GENERATOR OR MULTIPLE AEROSOLS

- AEROSOL FED INTO STORAGE BAG AND STORED AT 5×10^3 PARTICLES/CM^3
- PRIMARY DILUTION TO 5×10^3 PARTICLES/CM^3 OR MIXING RATIO OF MULTIPLE AEROSOLS ACCOMPLISHED WITH TIME-LINING
- FINAL DILUTION THROUGH FLOW CONTROL TO DOUBLE BAG
- HUMIDIFIED AIR AVAILABLE FOR GENERATION AND DILUTION TO PERMIT STORAGE IN DELIQUESCED STATE FOR NEAR AMBIENT SATURATOR

(2) STABLE GENERATOR

- BYPASS STORAGE BAG
- GENERATOR OUTPUT DIVIDED AND DILUTED IN FOUR STAGES. FACTOR OF 10^7 DILUTION AVAILABLE

(3) NEARLY STABLE GENERATOR (HIGH FREQUENCY FLUCTUATIONS)

- OPERATION AS WITH STABLE GENERATOR BUT PASS AEROSOL THROUGH STORAGE BAG OPERATING AS A PLENUM

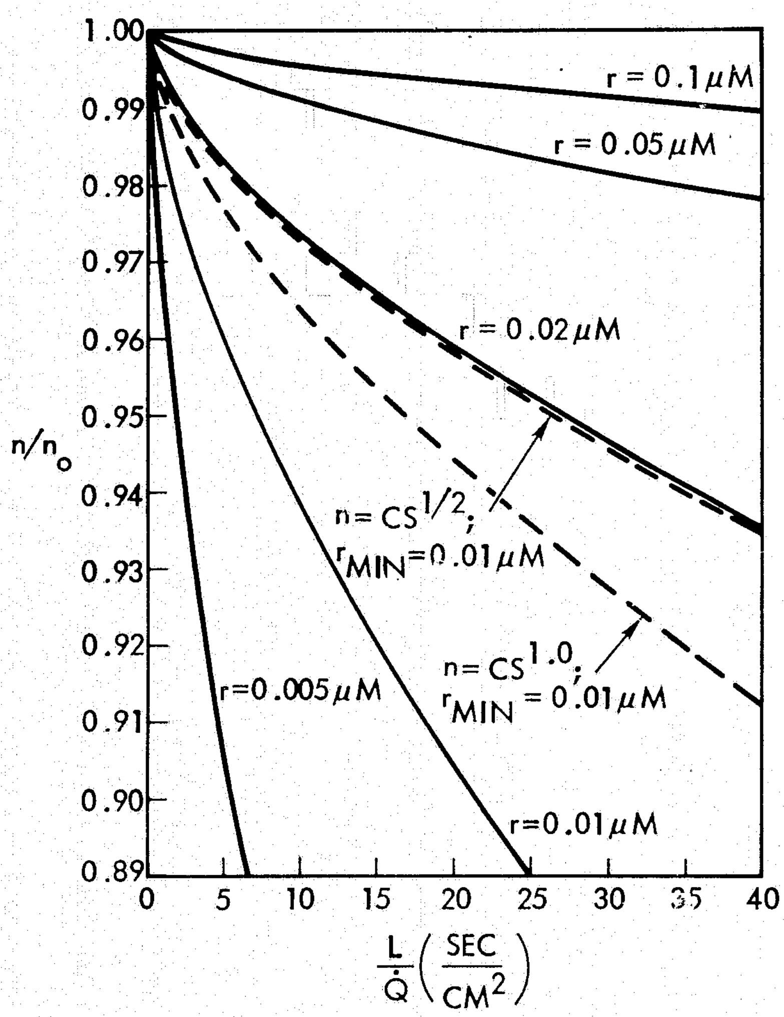
- FLOW CONTROL IN ALL OPERATING MODES IS THROUGH USE OF METERING VALVES ON DILUTION AIR. FIXED PRESSURE DIFFERENTIAL AND FLOW RESISTANCE ASSURES STABILITY.

TRW
SYSTEMS GROUP

Aerosol diffusion losses in the flow lines represent a major design problem in ACPL. Great care has been exercised in designing the Fluid Subsystem to control and minimize these losses where necessary. In particular, the flow rates through the saturator and to the experimental chambers have been set at high values to assure that the aerosol delivered to each chamber is as identical as possible.

FLUID SUBSYSTEM AEROSOL DIFFUSION LOSSES IN LINES

AEROSOL DIFFUSION LOSS IN LAMINAR FLOW THROUGH TUBES



- AEROSOL DIFFUSION LOSSES REPRESENT A MAJOR DESIGN PROBLEM IN ACPL
- TO MINIMIZE LOSSES FLOW LINES MUST BE KEPT SHORT AND FLOW RATES HIGH
- LINES HAVE BEEN SIZED FOR LAMINAR FLOW IN ALL AEROSOL LINES EXCEPT WHERE FLOW RATE IS VERY HIGH
- SPECIAL TREATMENT (PERFUSION FLOW) IS GIVEN TO SMALL SAMPLE FLOW TO CFD
- NO CONTROL COMPONENTS OTHER THAN FIXED ORIFICES AND HIGH CAPACITY VALVES IN THE AEROSOL LINES
- NO FLOW MEASUREMENTS MADE IN AEROSOL LINES TO EXPERIMENT
- TURBINE FLOWMETERS SELECTED OVER THERMAL FLOW METERS FOR MAXIMUM ACCURACY AND MINIMUM SENSITIVITY TO PARTICULATE FOULING

LEGEND
——— MONODISPERSE
– – – POLYDISPERSE

TRW SYSTEMS GROUP

Fluid Subsystem features pertaining to humidity measurement and control are listed on the facing page.

Humidity control throughout the system is accomplished passively and dessicant requirements are minimized through the use of air exchange with the cabin. Thus, the Spacelab resources (environmental control system) are utilized to reduce ACPL expendables.

FLUID SUBSYSTEM
HUMIDITY MEASUREMENT AND CONTROL

- SATURATOR DESIGNED FOR 99.99% RELATIVE HUMIDITY
- REHEAT ZONE IMMEDIATELY FOLLOWING HUMIDIFICATION ZONE LOWERS R.H. TO PREVENT DOWNSTREAM CONDENSATION
- SATURATOR OPERATED BELOW AMBIENT TEMPERATURE TO ASSURE NO DOWNSTREAM CONDENSATION DUE TO HEAT TRANSFER
- COMPONENTS BETWEEN SATURATOR AND EXPERIMENTAL CHAMBERS DESIGNED TO AVOID EXPANSIONS LEADING TO CONDENSATION
- RELATIVE HUMIDITY OF AEROSOL STREAM TO SATURATOR MEASURED TO PERMIT CALCULATION OF MIXING RATIO WITH DOWNSTREAM INJECTION
- HUMIDITY CONTROL OF RECIRCULATION FLOW ACCOMPLISHED PASSIVELY WITH CABIN BLEED. MINIMIZES DESSICANT REQUIREMENTS
- LOCAL DRYING OF AIR TO CFD AND SDL WITH DIFFUSION DRIERS

TRW SYSTEMS GROUP

Pressure and flow stability are of paramount importance to proper performance of the ACPL. In view of the Fluid Subsystem complexity, it has been simulated on TRW's analog computer to evaluate its steady state and transient performance. Analyses to date show the system to function within the stated requirements.

FLUID SUBSYSTEM
ANALOG COMPUTER SIMULATION

- ACPL FLUID SUBSYSTEM HAS BEEN SIMULATED ON TRW'S COMCOR 5000 ANALOG COMPUTER
- PROVIDES RAPID ANALYSIS OF SYSTEM PERFORMANCE DURING STEADY-STATE AND TRANSIENT OPERATIONS
- ANALYSES TO DATE INCLUDE:

  1) CHARACTERIZATION OF PUMP-INDUCED PRESSURE RIPPLE THROUGHOUT SYSTEM AS A FUNCTION OF PUMP SPEED AND PLENUM VOLUMES

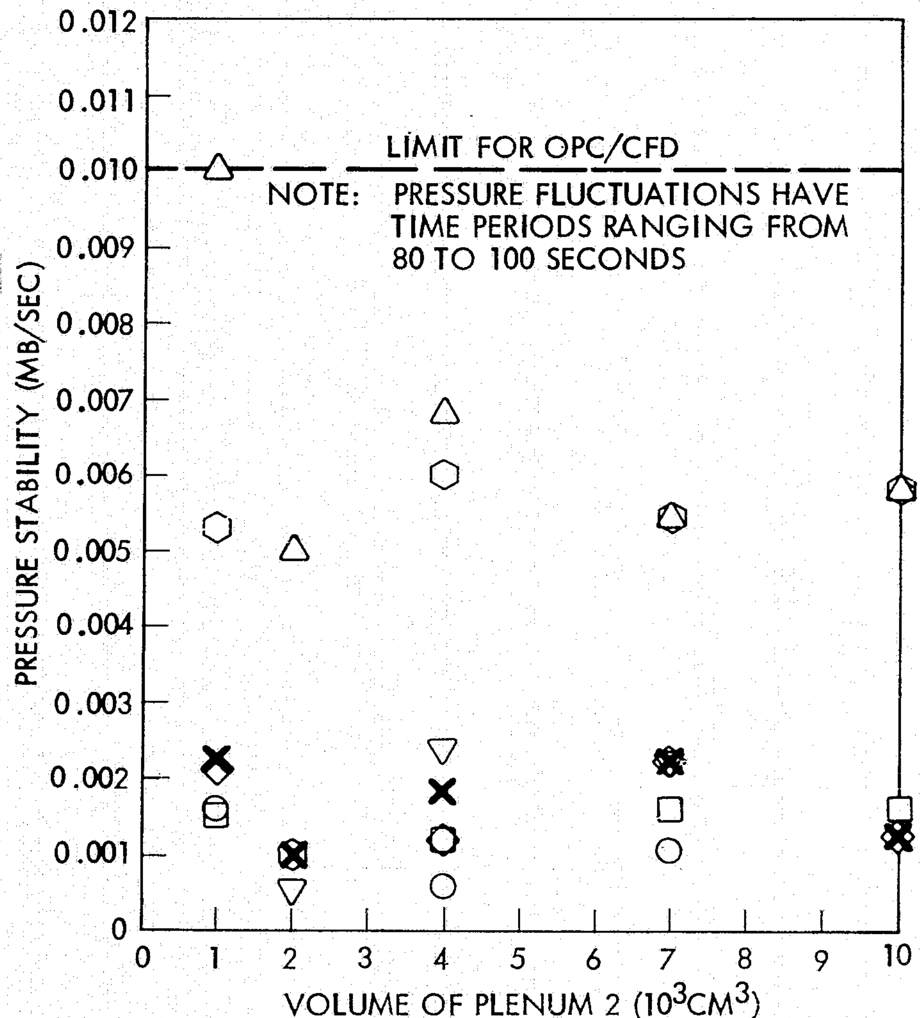
  2) STABILITY ANALYSIS FOR STEADY STATE OPERATION

  3) RESPONSE TO MAJOR FLOW TRANSIENTS (MEASURING AEROSOL SIZE DISTRIBUTION WITH THE EAA)

TRW
SYSTEMS GROUP

During steady state operation, analog simulation shows that the pressure in the saturator is stable to $\pm$ 0.1 mb compared with the $\pm$ 0.5 mb requirement. Also, the rate of pressure change in the CFD and OPC is only 0.002 mb/sec compared with the 0.01 mb/sec required to avoid transient supersaturations in excess of 0.001%.

ANALOG COMPUTER SIMULATION
STEADY STATE STABILITY



- STABILITY REQUIREMENTS ARE ACHIEVED: $\Delta P/\Delta T \sim 0.002$ MB/SEC IN CFD/OPC, FLUCTUATION AMPLITUDE IN SATURATOR $\sim \pm 0.1$ MB
- STABILITY NOT DEPENDENT ON PLENUMS
- PLENUM 1 - 1000 CM^3
- 500 SECOND PERIOD TAKEN ~ 150 SECONDS AFTER MAJOR TRANSIENT
- TEMPERATURE STABLE
- 1 SECOND TIME CONSTANTS FOR BOTH CONTROLLERS
- KEY

○ INLET PUMP

□ PLENUM 1

◇ SATURATOR

▽ EX. CH./SDL/EAS DOWNSTREAM LINE

△ PLENUM 2

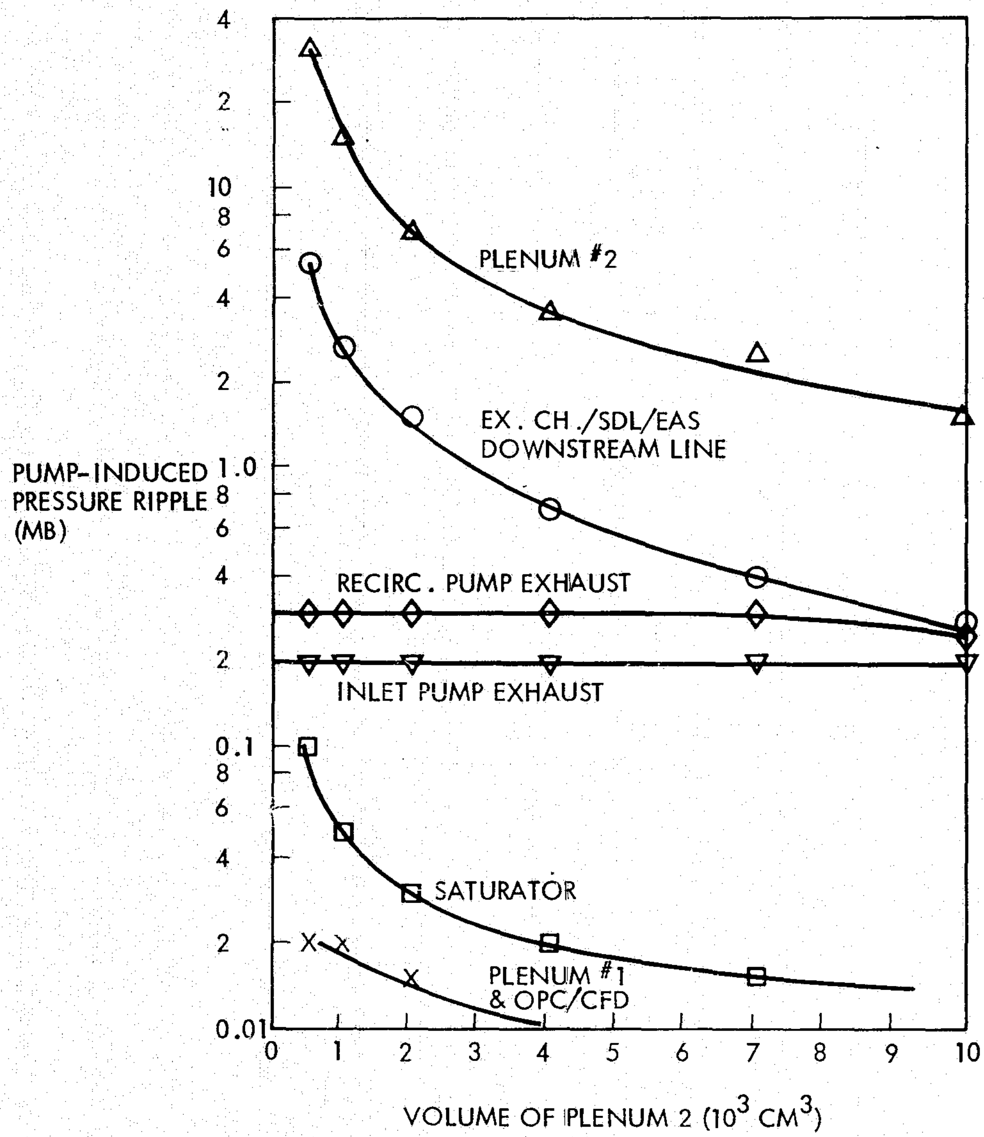
⬡ RECIRC. PUMP EXHAUST

✕ CFD/OPC

TRW SYSTEMS GROUP

Air circulation throughout the ACPL will be driven by diaphragm pumps to avoid particulate contamination. The pump-induced pressure ripple throughout the ACPL has been reduced to the required levels through selection of appropriate plenum volumes; i.e., one liter for plenum 1 and four liters for plenum 2.

ANALOG COMPUTER SIMULATION
PUMP INDUCED PRESSURE RIPPLE



ASSUMPTIONS

- PLENUM 1 - 1000 CM^3
- STEADY STATE VALUES
- INLET PUMP: 200 CM^3/SEC AT 800 RPM (13 HZ)
- RECIRCULATION PUMP: 1400 CM^3/SEC AT 3000 RPM (50 HZ)

RESULTS

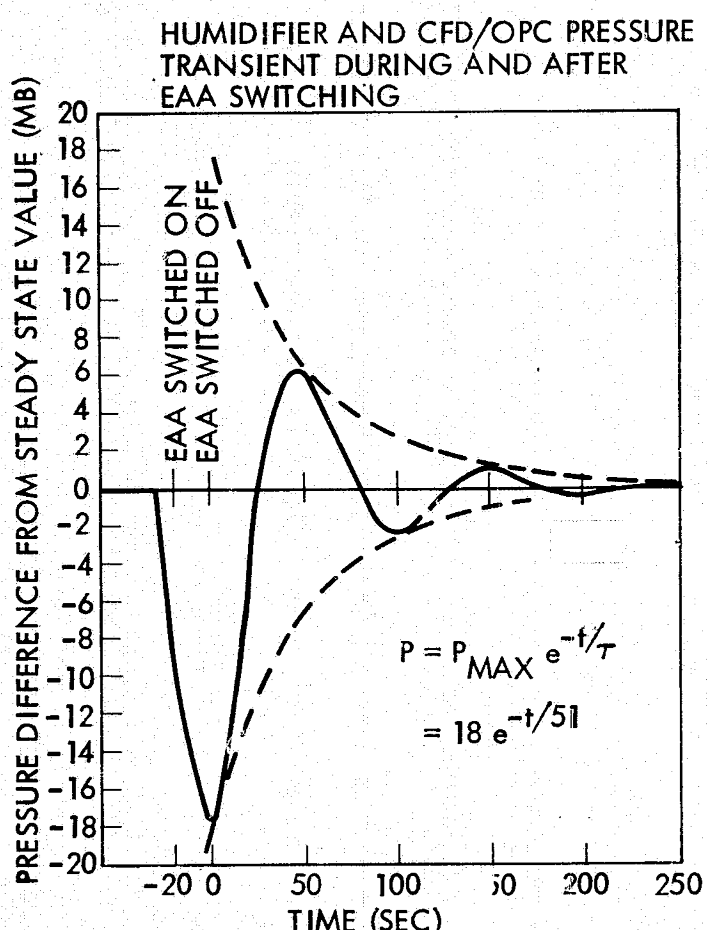
- ALL RIPPLES AT 50 HZ EXCEPT INLET PUMP EXHAUST AT 13 HZ
- INLET PUMP IS ISOLATED FROM SYSTEM
- PLENUM 2 VOLUME OF 4000 CM^3 REDUCES RIPPLE IN CFD/OPC TO ~0.01 MB
- HIGH FREQUENCY OF RIPPLE RENDERS IT INNOCUOUS

TRW SYSTEMS GROUP

Computer simulation of the major flow transient introduced when the 800 cm^3/sec sheath air flow to the EAA is switched in and out exhibits substantial pressure perturbations throughout the system. However, the system recovers to the required stability level within 200 seconds of the transient.

Our baseline approach is to plan the experiment time line to avoid major intermittent flow transients during critical periods such as flushing the expansion chamber and characterizing the aerosol in the CFD. An alternate approach would be to include a separate pump for the EAA sheath flow.

ANALOG COMPUTER SIMULATION RESPONSE TO MAJOR FLOW TRANSIENTS



ASSUMPTIONS:

- EAA SWITCHED ON FOR 30 SECONDS
- 1 SECOND TIME CONSTANTS FOR BOTH CONTROLLERS
- PLENUM 1 = 1000 CM^3, PLENUM 2 = 4000 CM^3

RESULTS:

- SUBSTANTIAL PRESSURE PERTURBATIONS WHEN EAA FLOW SWITCHED ON OR OFF
- SYSTEM RECOVERS TO REQUIRED STABILITY IN < 200 SECONDS WITH A TIME CONSTANT OF 51 SECONDS

CONCLUSIONS:

- PLAN EXPERIMENT TIME LINE TO AVOID MAJOR INTERMITTENT FLOW TRANSIENTS DURING CRITICAL PERIODS SUCH AS CHAMBER FLUSHING OR CFD OPERATION
- ALTERNATE OPTION – UTILIZE SEPARATE PUMP FOR EAA SHEATH AIR FLOW

TRW SYSTEMS GROUP

Commercially available equipment has been identified for most of the Fluid Subsystem components. Most of this equipment requires little or no modification for use on ACPL.

FLUID SUBSYSTEM
IDENTIFIED COMMERCIAL EQUIPMENT

- PUMPS, AIR-INLET AND RECIRCULATION, DIAPHRAGM
- DIFFUSION DRYERS, DESICCANT
- SOLENOID VALVES, TWO AND THREE WAY
- SERVO CONTROLLED METERING VALVES
- PRESSURE TRANSDUCERS, ABSOLUTE AND DIFFERENTIAL
- RELATIVE HUMIDITY SENSOR
- ADJUSTABLE ORIFICES, MANUAL METERING VALVES
- FIXED ORIFICES
- TURBINE FLOWMETERS
- FITTINGS, TUBING

TRW
SYSTEMS GROUP

The major considerations in designing the saturator relate to the internal configuration for saturation and reheat, wick contamination effects, the wick system for water supply and thermal control.

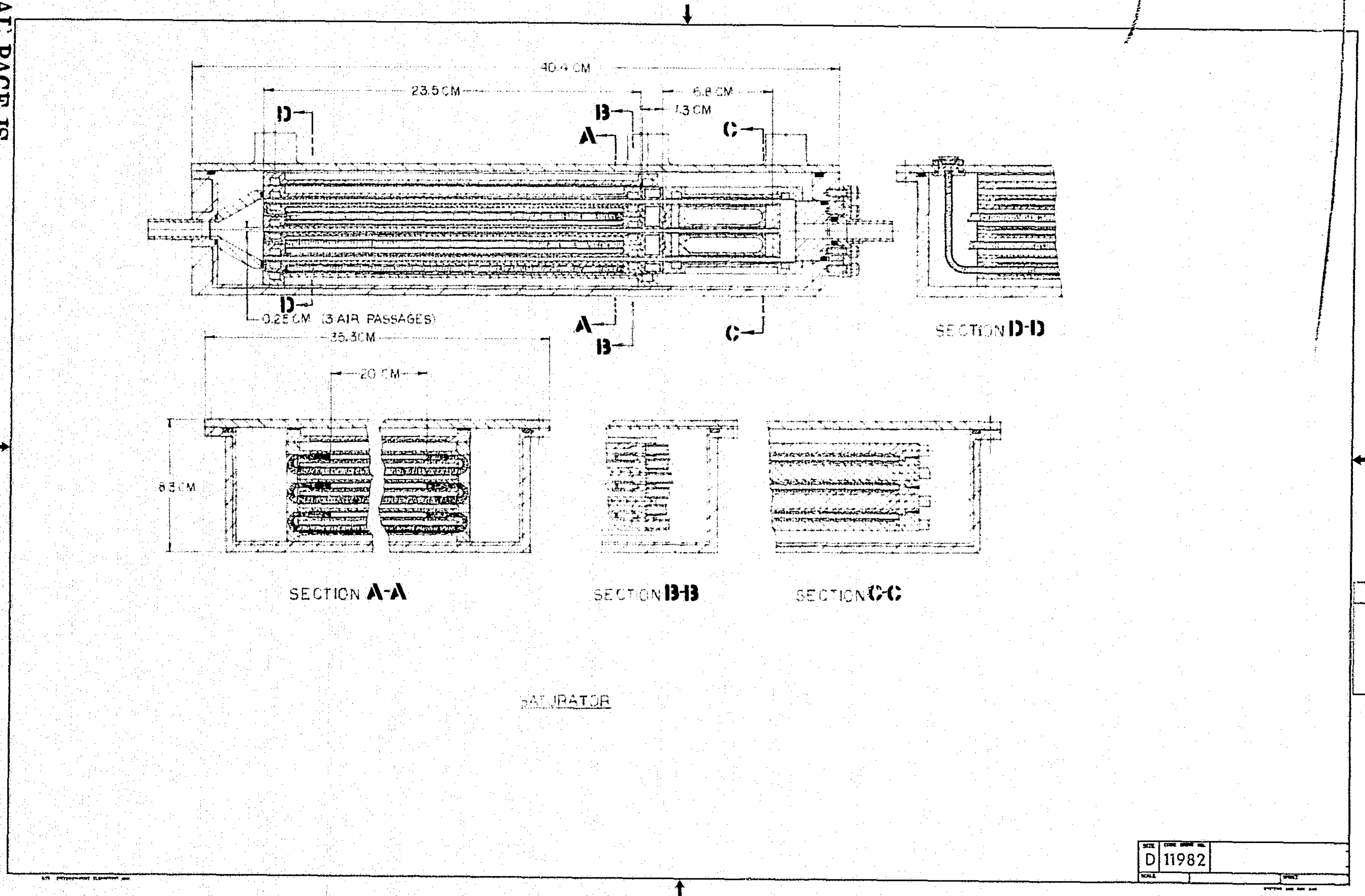
SATURATOR DESIGN ELEMENTS

- INTERNAL CONFIGURATION FOR SATURATION AND REHEAT
- WICK CONTAMINATION
- WICK SYSTEM
- THERMAL CONTROL

TRW
SYSTEMS GROUP

A preliminary design layout of the saturator is shown on the facing page. The saturation and reheat sections have been combined in a single package. Other features of the design are described on the following pages.

SATURATOR LAYOUT



The requirements and objectives pertaining to the design of the saturator internal configuration are as listed. All of these are met or exceeded by the recommended design with the possible exception of the absolute accuracy in water vapor mixing ratio.

INTERNAL CONFIGURATION

REQUIREMENTS AND OBJECTIVES

- AIR FLOW RATE 400 - 1200 CM^3/SEC
- DEW POINT TEMPERATURE RANGE 0.5 - 20°C
- RELATIVE HUMIDITY AT OUTLET OF REHEATER 50 - 99 PERCENT
- AEROSOL INJECTION UPSTREAM OR DOWNSTREAM
- REFERENCE PRESSURE:

REFERENCE PRESSURE:	ABSOLUTE ACCURACY	±1.0 mb
	STABILITY	±0.5 mb
	RELATIVE ACCURACY	±0.1 mb

- WATER VAPOR MIXING RATIO KNOWN TO ±0.5% FOR DEW POINTS ABOVE 0.5°C

TRW SYSTEMS GROUP

The humidification concept is to saturate air in flow over wet surfaces at known conditions and then heat it over dry surfaces to lower its relative humidity without altering the mixing ratio.

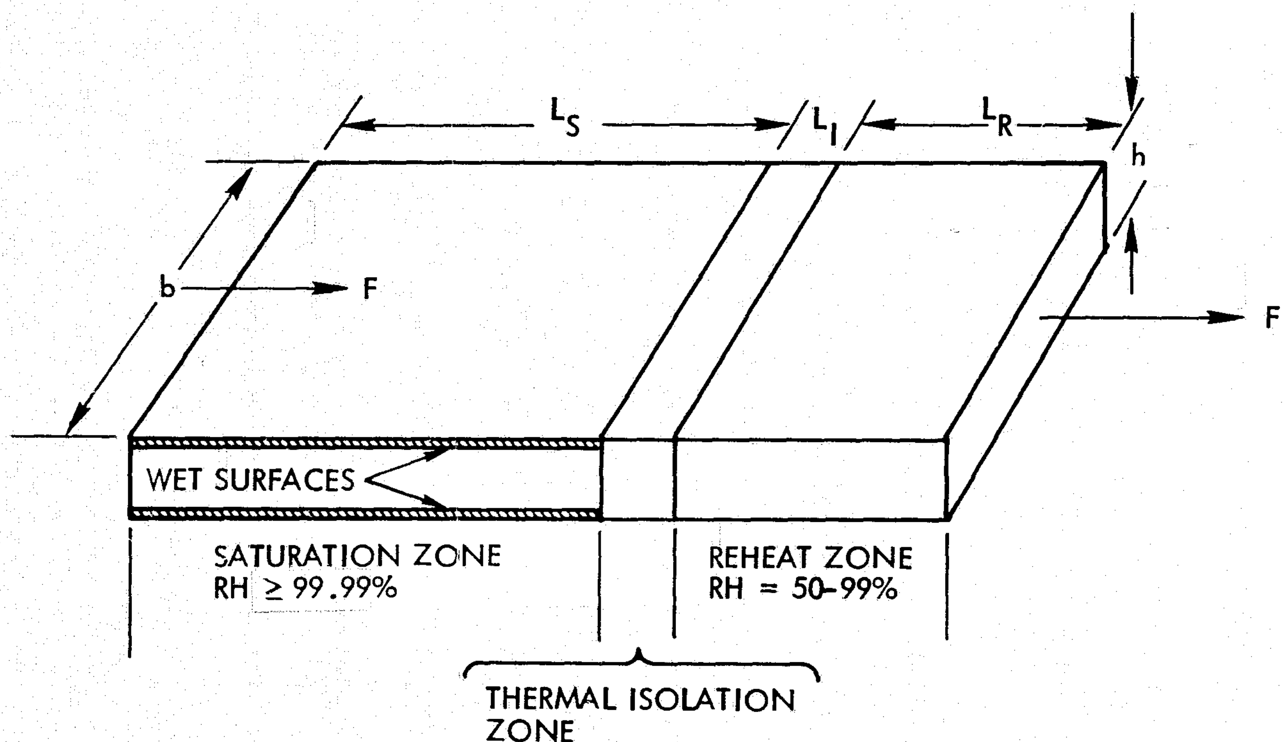
Trade studies show that flow in high aspect ratio ducts is simpler to implement than flow in tubes.

The saturation and reheat zones are separated by an isolation zone which prevents thermal distrubance of the reference zone at the end of the wet surfaces by the hotter reheater plates. The plate surfaces in this isolation zone are designed as capillary barriers to prevent water from wetting the dry reheater plates.

INTERNAL CONFIGURATION

- SATURATE AIR IN FLOW OVER WET SURFACES AT KNOWN TEMPERATURE AND PRESSURE, AND THEN HEAT IT OVER DRY SURFACES TO LOWER RELATIVE HUMIDITY AND PREVENT DOWNSTREAM CONDENSATION

- FLOW IN HIGH ASPECT RATIO RECTANGULAR DUCTS SIMPLER TO IMPLEMENT THAN FLOW IN TUBES



TRW SYSTEMS GROUP

The design guidelines used in sizing the saturator are listed on the facing page. Key among them are:

- The length of the saturation zone has been designed for 99.99% relative humidity so that incomplete saturation does not significantly contribute to the uncertainty in the mixing ratio.
- The design has been constrained to assure a flow pressure drop along the channels less than 0.1 mb. This assures that the pressure drop does not significantly contribute to uncertainty in the mixing ratio.
- The saturator is designed for a total flow of 1000 cm^3/sec to minimize aerosol diffusion losses and facilitate expansion chamber flushing.

INTERNAL CONFIGURATION

- SATURATION LENGTH GIVEN BY GRAETZ SOLUTION: FOR RH = 99.99% AT 0.5°C (WORST CASE), $L_S = 5.64\ Fh/b$
- THERMAL ISOLATION LENGTH DETERMINED BY NUMERICAL MODELLING: $L_I = 1.27$ CM PERTURBS REFERENCE TEMPERATURE < 0.0015°C FOR 20°C REHEAT WITH 0.178 CM PLATE THICKNESS
- REHEATER LENGTH SIZED FOR 95 PERCENT EFFECTIVENESS: AT 0.5°C (WORST CASE), $L_R = 3\tau_W = 1.63\ Fh/b$
- INTERNAL DIMENSIONS AND NUMBER OF CHANNELS SELECTED TO ASSURE FLOW PRESSURE DROP ≤0.1 mb

  $\Delta P = 2.212 \times 10^{-6}\ FL/bh^3$ AT 20°C (WORST CASE)
- OVERALL LENGTH OF PLATES ≤50 CM FOR PACKAGING
- SATURATION LENGTH ≥20 CM FOR THERMAL CONTROL OF REFERENCE ZONE
- DESIGN FOR TOTAL FLOW OF 1000 CM^3/SEC TO MINIMIZE AEROSOL DIFFUSION LOSSES IN LINES AND TO FACILITATE EXPANSION CHAMBER FLUSHING

TRW
SYSTEMS GROUP

The facing table shows a series of saturator designs with the number of flow channels, channel width and plate spacing as parameters.

The design selected utilizes three flow channels with 0.25 cm plate spacing, 20 cm width and 31.55 cm overall length. This selection satisfies all of the design guidelines with minimum length and width.

INTERNAL CONFIGURATION MATRIX
(TOTAL FLOW = 1000 CM^3/SEC)

NUMBER OF CHANNELS N	F CM^3/SEC	b CM	h CM	L_S CM	L_I CM	L_R CM	L CM	ΔP mb	
2	500	30	0.5	47.00	1.27	13.59	61.86	0.018	
		30	0.3	28.20	1.27	8.15	37.62	0.052	
		30	0.15	14.10	1.27	4.08	19.45	0.212	
		20	0.3	42.30	1.27	12.23	55.80	0.114	
		20	0.15	21.15	1.27	6.12	28.54	0.460	
3	333.3	30	0.5	31.33	1.27	9.05	41.65	0.008	
		30	0.3	18.80	1.27	5.44	25.51	0.023	
		30	0.15	9.40	1.27	2.71	13.38	0.098	
		20	0.3	28.20	1.27	8.15	37.62	0.052	
		20	0.25	23.49	1.27	6.79	31.55	0.075	*
		20	0.15	14.10	1.27	4.07	19.44	0.212	
		15	0.25	31.33	1.27	9.05	41.65	0.131	

VIOLATES DESIGN GUIDELINES

* SELECT N = 3, b = 20 CM, h = 0.25 CM, L = 31.55 CM SATISFIES ALL GUIDELINES WITH MINIMUM LENGTH AND WIDTH

TRW SYSTEMS GROUP

There has been considerable concern expressed over possible contamination of the wicks causing a reduction in vapor pressure of the water and an error in mixing ratio. This concern has led to the requirement for a downstream aerosol injection option and for irrigation of the wicks in the reference zone.

The primary concern has been with regard to diffusive deposition of the aerosol on the wick surfaces. However, one must also be concerned with other sources of contamination such as water impurities, trace gas impurities, etc.

WICK CONTAMINATION

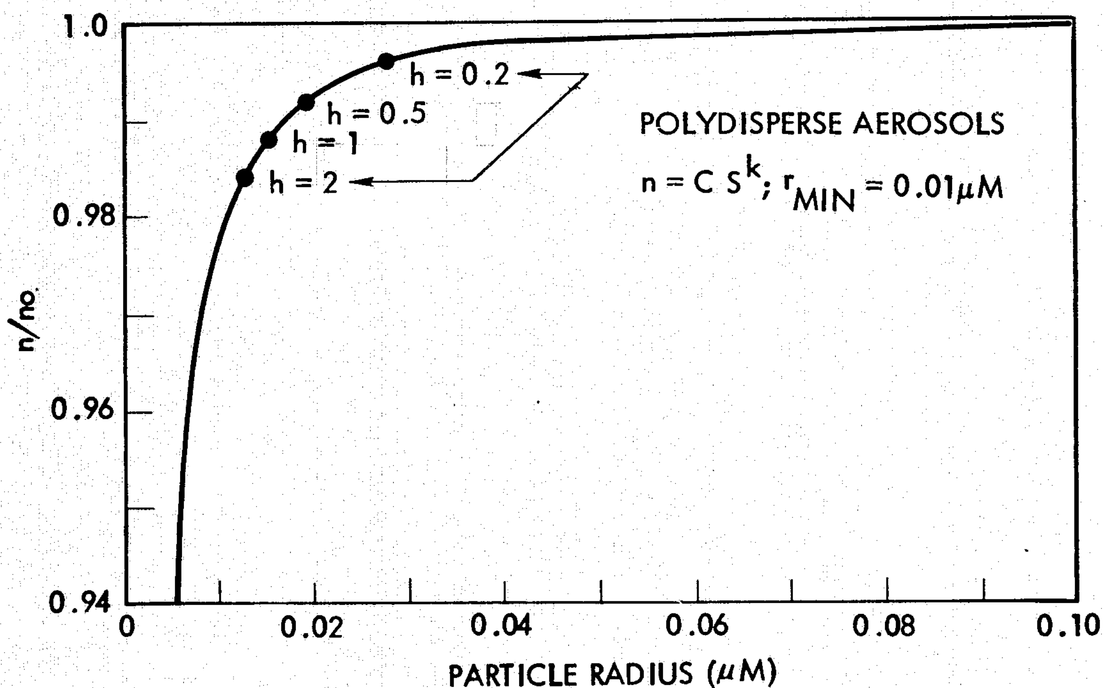
OBJECTIVE:

AEROSOL DEPOSITION ON WICK SURFACES SHALL NOT ALTER VAPOR PRESSURE AT REFERENCE POINT SO AS TO PRECLUDE ±0.5% ACCURACY IN MIXING RATIO

TRW SYSTEMS GROUP

An analysis of aerosol diffusion losses in TRW's recommended saturator design shows that very little aerosol is deposited on the wicks.

AEROSOL DIFFUSION LOSS IN SATURATOR



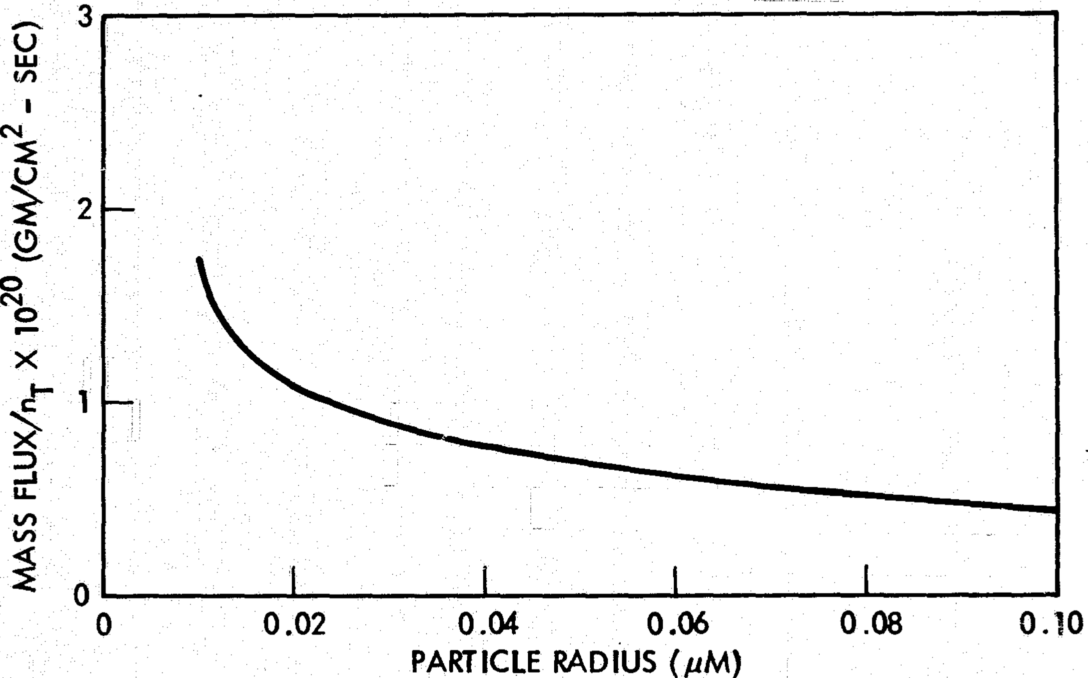
- FOR RECOMMENDED DESIGN
- $\bar{D} = \frac{3k}{3k+4} D (r_{min})$
- NEGLECTS DELIQUESCENCE

- MONODISPERSE AEROSOL LOSS < 2.3%
- POLYDISPERSE AEROSOL LOSS < 1.2% FOR $0.5 \leq k \leq 1.0$

TRW SYSTEMS GROUP

For the aerosol loss rates calculated, the mass flux to the wick in the reference region is extremely small. A typical sodium chloride aerosol with 1000 particles/cm^3 would results in a deposition flux of only 7.7×10^{-17} gm/cm^2-sec.

DIFFUSIVE MASS DEPOSITION OF AEROSOL ON SATURATOR WICKS



- MASS FLUX AT REFERENCE POINT
- NaCl AEROSOL
- $N = CS^{1/2}$, $r_{min} = 0.01\ \mu M$
- FOR n_T = 1000 PARTICLES/CM^3, $M'' = 7.7 \times 10^{-17}$ GM/CM^2 - SEC
- MOST OF MASS DEPOSITED BY SMALLER PARTICLES

TRW SYSTEMS GROUP

The effect of the deposited sodium chloride on the uncertainty in mixing ratio is less than 10^{-7} percent, which is negligible.

However, possible contamination by surfactants which concentrate at the water surface still warrants irrigation of the wicks at the saturator reference zone.

EFFECT ON MIXING RATIO

- DEPOSITED MASS IN 48 HOURS CONTINUOUS OPERATION

  $$M = 1.33 \times 10^{-11} \text{ GM/CM}^2$$

- MAXIMUM CONCENTRATION OF NaCl (NEGLECTING IRRIGATION)

  $$C \leq 1.05 \times 10^{-9} \text{ GM/CM}^3$$

- DEPRESSION OF VAPOR PRESSURE EQUAL TO MOLE FRACTION OF SOLUTE BY RAOULT'S LAW

  $$\frac{\Delta P_v}{P_v} = \frac{\text{MOLES NaCl}}{\text{MOLES SOLUTION}} \leq 5.8 \times 10^{-10}$$

- MAXIMUM EFFECT ON MIXING RATIO $< 10^{-7}$ PERCENT
- AEROSOL DEPOSITION HAS NEGLIGIBLE EFFECT
- POSSIBLE CONTAMINATION BY SURFACTANTS STILL WARRANTS IRRIGATION OF REFERENCE ZONE

TRW SYSTEMS GROUP

The requirements and objectives pertaining to the wick system design are listed on the facing page. All except the objective to store sufficient water for an entire mission are concerned with minimizing the uncertainty in mixing ratio due to temperature uncertainty, capillarity and contamination effects on the water vapor pressure.

SATURATOR WICKING SYSTEM

REQUIREMENTS AND OBJECTIVES:

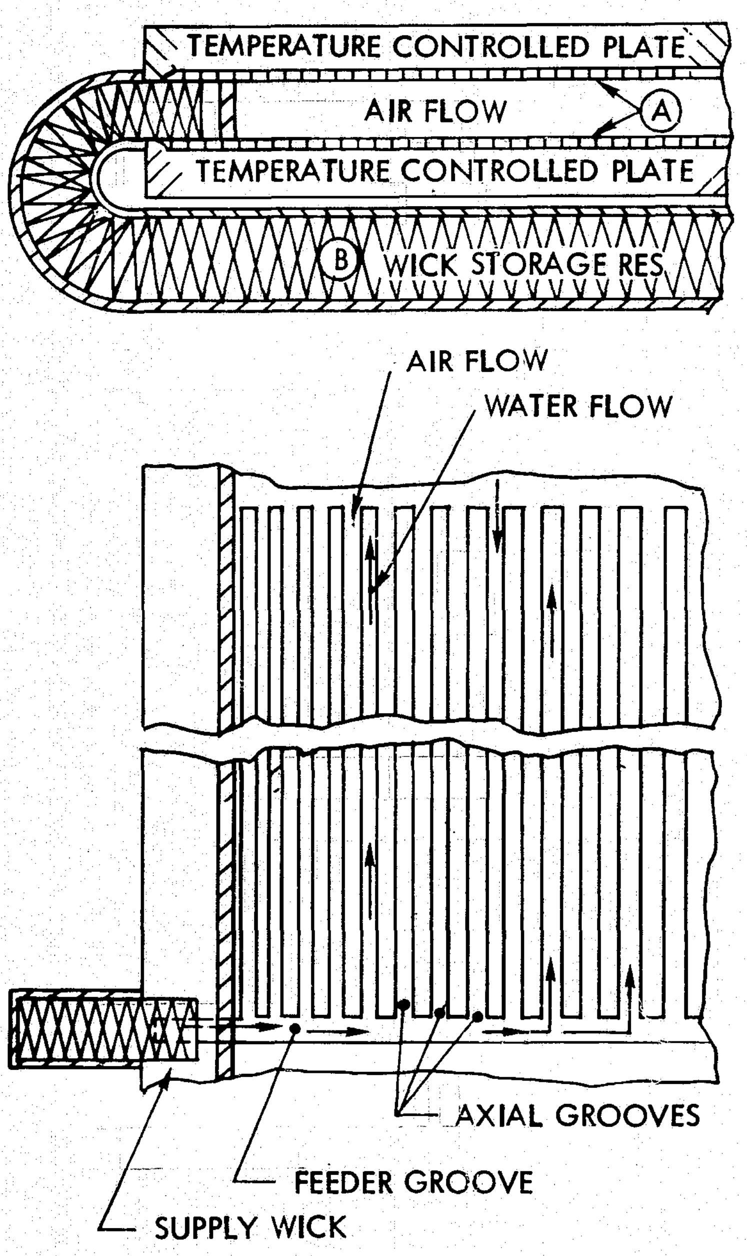
- MINIMUM TEMPERATURE DROP ACROSS WICKS
- IRRIGATION (NO STAGNATION) OF REFERENCE ZONE
- STORE SUFFICIENT WATER FOR ENTIRE MISSION
- MINIMIZE INFLUENCE OF CAPILLARITY ON VAPOR PRESSURE

TRW
SYSTEMS GROUP

The wick system selected incorporates capillary grooves machined directly into the plate surfaces with water flow from the reference zone toward the air inlet region. This design provides extremely small wick temperature drops and promotes excellent irrigation of the surface liquid in the reference zone.

The water for humidification is stored in temperature controlled reservoirs to eliminate temperature disturbance of the reference zone as it flows onto the plates. The reservoirs are sized to store sufficient water for an entire mission.

RECOMMENDED WICKING SYSTEM



A) AXIAL RECTANGULAR GROOVES MACHINED INTO PLATE PROVIDE MINIMUM TEMPERATURE DROP AND GOOD IRRIGATION OF REFERENCE ZONE (NO STAGNATION)

B) GRADED POROSITY WICKS TO CONTROL WATER LOCATION IN STORAGE RESERVOIRS. 500 CM^3 STORAGE VOLUME PROVIDES 65 PERCENT CONTINGENCY FACTOR FOR CONTINUOUS OPERATION OVER 48 HOURS WITH 90 PERCENT RH INLET

- STORAGE RESERVOIRS IN TEMPERATURE CONTROLLED REGION TO AVOID TEMPERATURE PERTURBATION OF REFERENCE ZONE BY WATER SUPPLY
- STORAGE RESERVOIRS VENTED TO AIR STREAM (NOT SHOWN) MAKES WICK SYSTEM INSENSITIVE TO PRESSURE LEVEL

TRW SYSTEMS GROUP

The wick system selected operates with very little capillary stress so that capillary effects on the mixing ratio are negligible. The capillary stress is sufficient, however, to pump the required liquid and overcome the shear forces of the counterflowing vapor.

CAPILLARY STRESS IN WICKS

- AXIAL GROOVES: DIMENSIONS 0.025 X 0.025 CM
  SPACING 0.025 CM
- MAXIMUM CAPILLARY PRESSURE: 5.6 CM H_2O
- MAXIMUM WICK STRESS: ZERO-G = 0.5 CM H_2O
  ONE-G = 0.9 CM H_2O
- VAPOR SHEAR ON LIQUID IN GROOVES: 0.06 PERCENT OF CAPILLARY FORCE
- VAPOR PRESSURE REDUCTION BY CAPILLARY STRESS: $<10^{-4}\%$
- CAPILLARY EFFECT ON MIXING RATIO: $<10^{-4}\%$

TRW SYSTEMS GROUP

The thermal control requirements and objectives for the Saturator are as shown. All of these can be readily met with the recommended design except for the requirement on mixing ratio uncertainty.

We have previously shown that the contributions of incomplete saturation (10^{-2}%), pressure drop (10^{-2}%), aerosol deposition (10^{-7}%) and capillarity (10^{-4}%) on the mixing ratio uncertainty are negligible. This leaves only absolute pressure and temperature accuracy as significant effects. The accuracy requirement on absolute pressure of $\pm$ 0.5 mb corresponds to a mixing ratio uncertainty of 0.05%. However, the required $\pm$ 0.1°C absolute temperature accuracy yields an uncertainty contribution of $\pm$ 0.7%. Thus, to know the mixing ratio to within $\pm$ 0.5% requires measuring the absolute temperature with an accuracy better than $\pm$ 0.07°C, which exceeds the stated requirement and may also exceed the state-of-the-art.

Dew point operation down to -25°C can be achieved in two ways. First, the Saturator can be operated at -25°C for several hours without exhausting the sublimating ice stored in the wicks. Second, the Fluid Subsystem provides for splitting the flow and partially bypassing the Saturator. In this mode the Saturator will be operated above 0°C and lower dew points established by controlling the fraction of bypass flow.

THERMAL CONTROL

REQUIREMENTS AND OBJECTIVES:

- OPERATING TEMPERATURE RANGE: DEW POINT $0.5 \leq T_S \leq 20°C$
  REHEAT $0.5 \leq T_R \leq 30°C$
- REFERENCE ZONE TEMPERATURE: ABSOLUTE ACCURACY ±0.1°C
  STABILITY ±0.02°C
  RELATIVE ACCURACY ±0.01°C
- NO CONDENSATION DOWNSTREAM OF SATURATOR
- MIXING RATIO KNOWN TO ±0.5% (T KNOWN TO ±0.07°C) (ABSOLUTE ACCURACY OF 0.1°C→±0.7% MIXING RATIO ERROR)

GROWTH POTENTIAL

- DEW POINTS TO -25°C KNOWN TO ±1°C
- MIXING RATIO KNOWN TO ±0.1% (T KNOWN TO < ±0.014°C)

TRW
SYSTEMS GROUP

The recommended approach to thermal control of the saturator is similar to that used for the CFD and SDL; a pumped coolant loop. Aside from its simplicity and proven performance, a significant advantage of the pumped coolant approach is that all of the saturator plates are simultaneously controlled by the same coolant. Thus, temperature control of all plates is obtained with a single control circuit. There is no need to match the temperatures of multiple, independently controlled plates. This reduces the number of control circuits required.

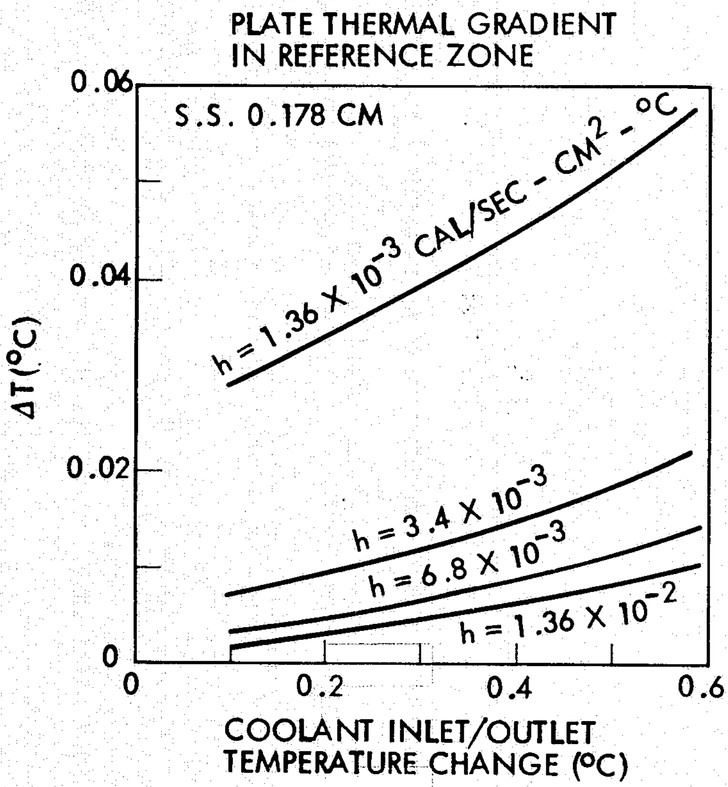
THERMAL CONTROL APPROACH

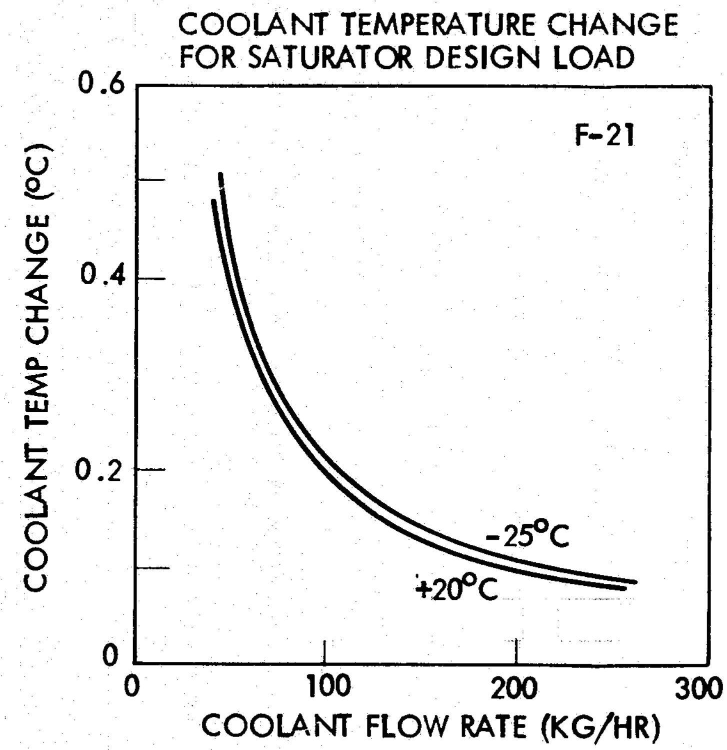
- PUMPED FREON IN COUNTERFLOW TO AIR STREAM PROVIDES MAXIMUM CONTROL IN REFERENCE ZONE, UNIFORMITY BETWEEN PLATES AND TEMPERATURE STABILITY. CAPABLE OF OPERATION TO -25°C
- TEMPERATURE CONTROLLED GUARD PLATES ISOLATE SATURATION ZONE FROM AMBIENT
- THERMAL MODELLING SHOWS REQUIRED PLATE UNIFORMITY IS ACHIEVED
- MATCHED AND CALIBRATED THERMISTORS MEET INITIAL MEASUREMENT REQUIREMENTS

TRW
SYSTEMS GROUP

Thermal modelling of the saturator plates shows that excellent temperature uniformity in the reference region can be achieved with reasonable Freon-21 coolant flow rates and heat transfer coefficients.

THERMAL ANALYSIS





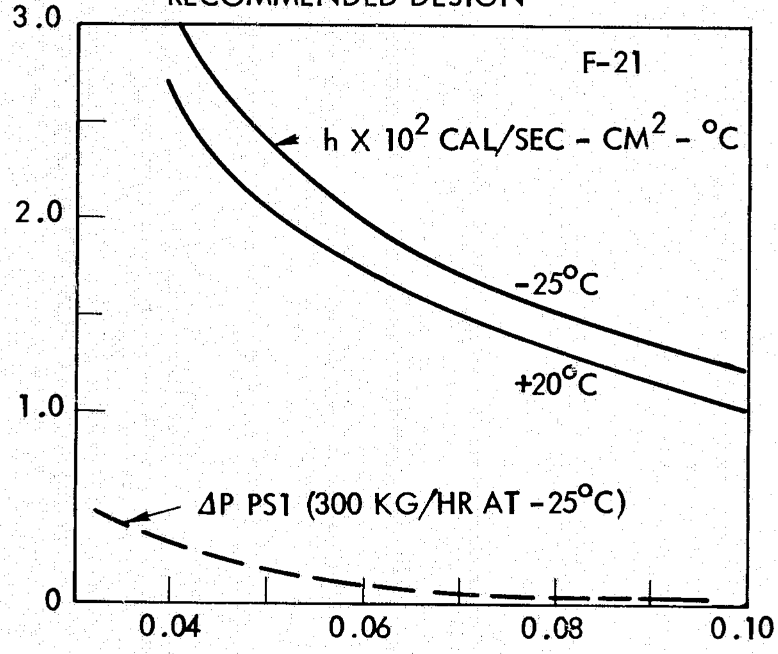
- REFERENCE ZONE UNIFORMITY BECOMES INSENSITIVE TO COEFFCIENT OF HEAT TRANSFER ABOVE 6.8×10^{-3} CAL/SEC-CM^2 - °C
- COOLANT FLOW RATE $\geq$ 50 KG/HR YIELDS $<$ 0.010° GRADIENT IN REFERENCE ZONE

TRW
SYSTEMS GROUP

The saturator plates have been designed with a flow channel height of 0.1 cm. This yields a sufficiently high heat transfer coefficient and low coolant pressure drop that 0.004°C axial temperature uniformity in the reference zone can be achieved with very low pump power using a nominal coolant flow of 100 kg/hr (0.32 GPM).

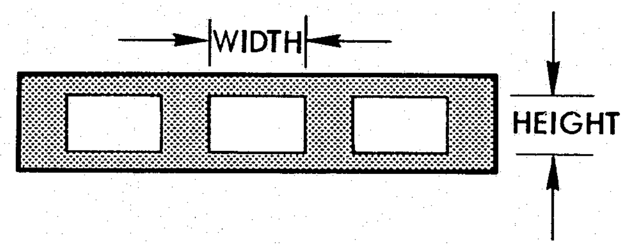
THERMAL ANALYSIS

HEAT TRANSFER COEFFICIENT AND COOLANT PRESSURE DROP FOR RECOMMENDED DESIGN



CHANNEL WIDTH - 0.55 CM

CHANNEL LENGTH - 23.5 CM



- DESIGN FOR CHANNEL HEIGHT = 0.10 CM
- $h \geq 1.0 \times 10^{-2}$ CAL/SEC - CM^2 - °C
- CHANNEL PRESSURE DROP NEGLIGIBLE
- COOLANT FLOW OF 100 KG/HR (0.32 GPM) YIELDS 0.004°C AXIAL UNIFORMITY IN REFERENCE ZONE

TRW SYSTEMS GROUP

The facing page summarizes the key features of the recommended saturator design.

SATURATOR SUMMARY

- 3 CHANNEL SYSTEM YIELDS 99.99 PERCENT RH FOR $F = 1000\ CM^3/SEC$ WITH <0.1 mb PRESSURE DROP
- AEROSOL DEPOSITION ON WICKS HAS NEGLIGIBLE EFFECT ON MIXING RATIO
- WICK SYSTEM PROVIDES WATER STORAGE FOR ENTIRE MISSION AND IRRIGATION OF REFERENCE ZONE WITH TEMPERATURE CONTROLLED FEED WATER
- PUMPED FLUID THERMAL CONTROL SYSTEM ASSURES EQUAL PLATE TEMPERATURES, REFERENCE ZONE UNIFORMITY AND TEMPERATURE STABILITY CONSISTENT WITH REQUIREMENTS
- DESIGN MEETS ALL REQUIREMENTS AND OBJECTIVES FOR INITIAL ACPL, EXCEPT MIXING RATIO ACCURACY, AND PROVIDES GROWTH POTENTIAL

TRW
SYSTEMS GROUP

PRECEDING PAGE BLANK NOT FILMED

CONTROL AND DATA SUBSYSTEM

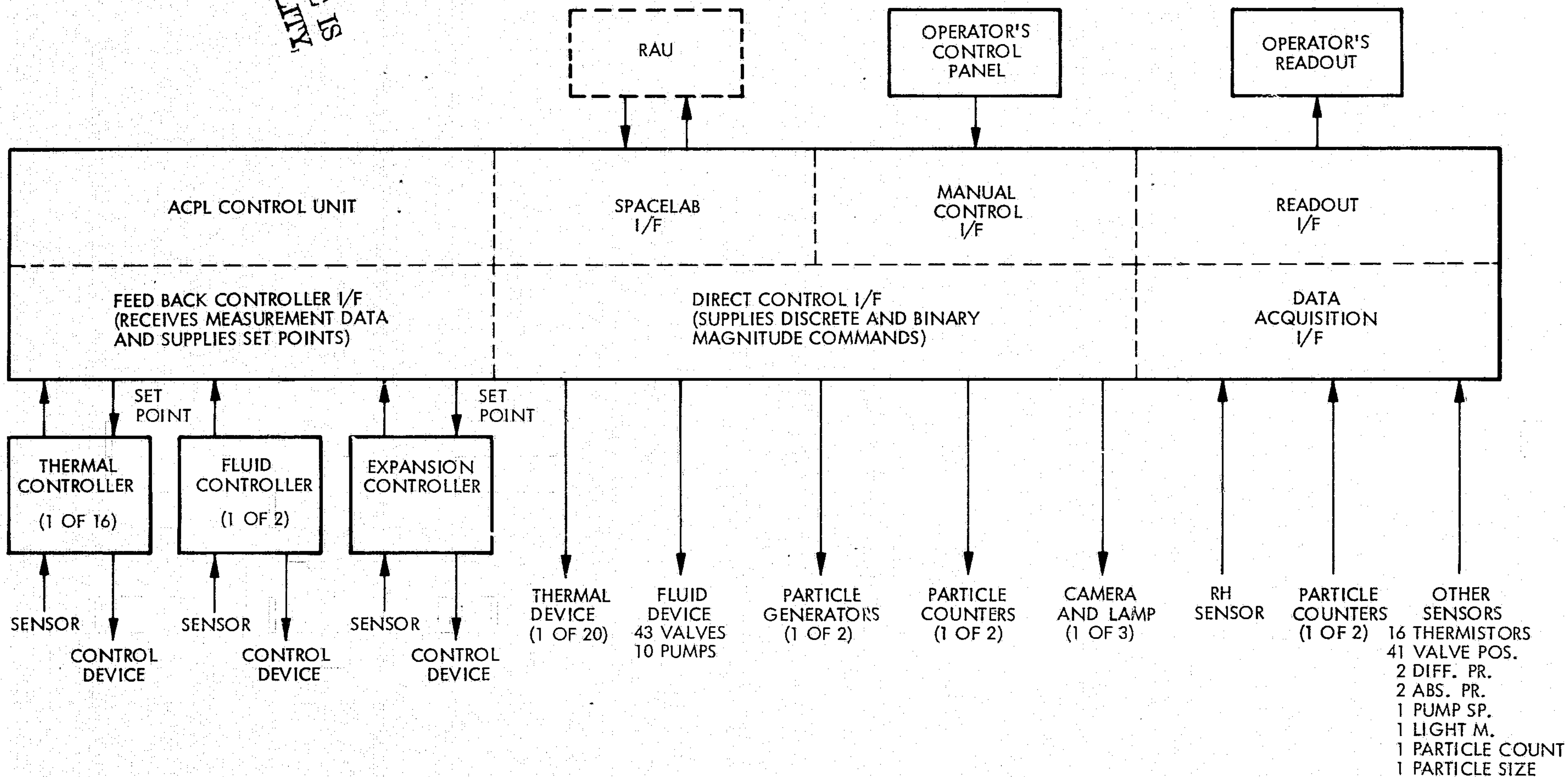
TRW SYSTEMS GROUP

CONTROL AND DATA SUBSYSTEM BLOCK DIAGRAM

The block diagram shows the major functions of the control and data subsystem. Most of the data inputs and command outputs are identified as CAMAC modules.

In the absence of the Space Lab computer, limited operator controls and readouts will be available through local measuring instruments. In the presence of the Space Lab computer, all sensor data will be telemetered to the computer and all valve states will be reported where the valves are equipped for this purpose. Servo loops are closed locally to maintain ACPL integrity during computer outages to avoid problems with the one second time share period and limit demands on computing time. Set point data can be updated during each time share period as can be open loop pressure and temperature controls.

CONTROL AND DATA BLOCK DIAGRAM



TRW
SYSTEMS GROUP

BASELINE CAMAC MODULES

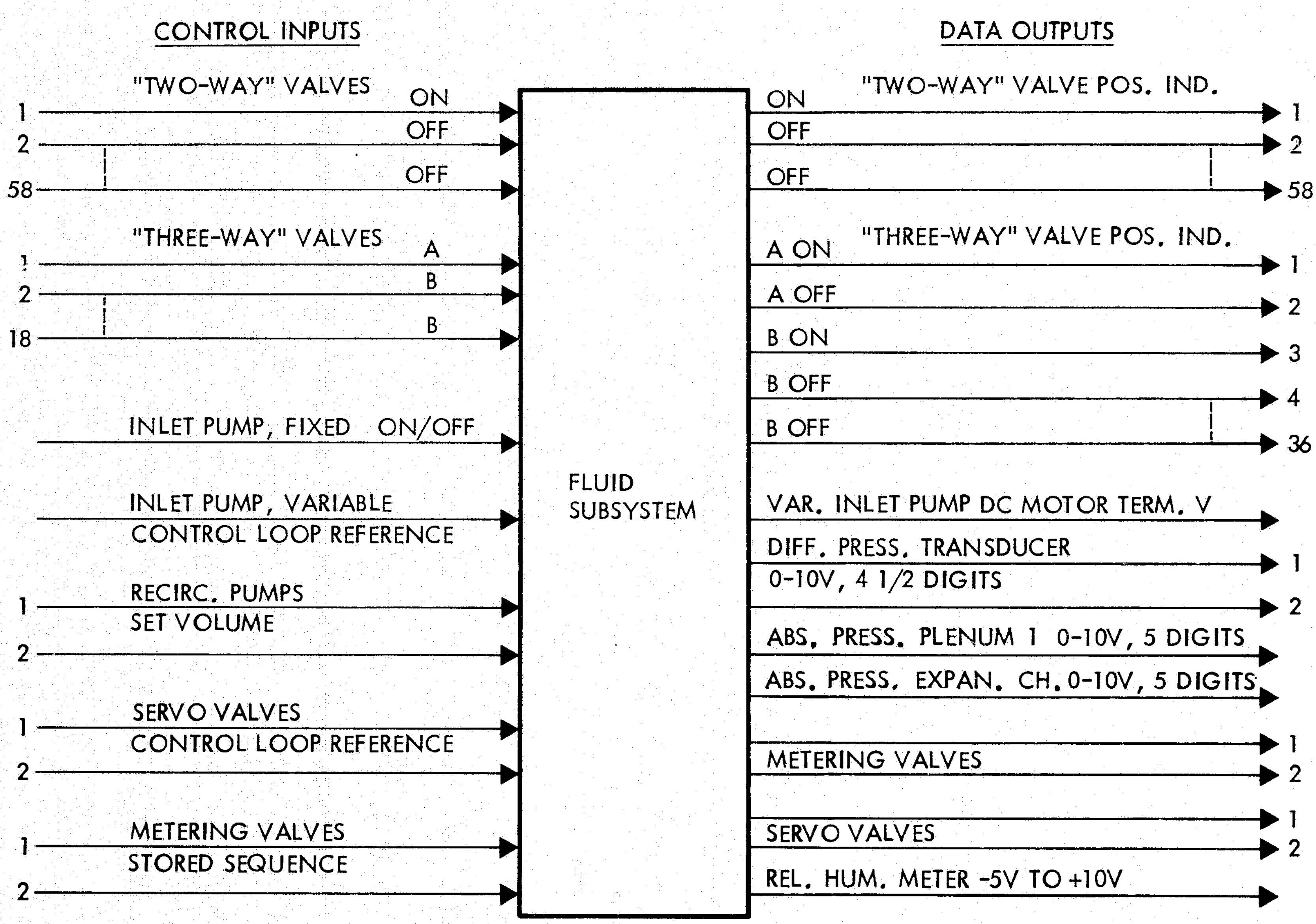
VENDOR MODULE NUMBER	NUMBER REQUIRED	FUNCTION	TOTAL MODIFIED DC POWER (WATTS)	APPLICATION
3060	3	32 BIT INPUT GATE	12	SENSE VALVE STATE
3080	1	8 BIT TRIAC OUTPUT	.9	CONTROL MOTORS
3082	1	12 BIT TRANSISTOR OUTPUT	1.3	LED DISPLAY
3094	7	16 BIT ISOL. CONTACT OUTPUT	19	CONTROL VALVES
3112/A	2	8-CH, 12 BIT D/A	6.4	REFERENCE TO LOOPS
3512	2	16-CH, SCANNING ADC (12B)	1.9	DATA INPUT
RTC 018	1	REAL TIME CLOCK	1.5	TIMING
	1	CRATE CONTROLLER	4.5	RAU I/F
			47.5	
		ASSUMING 60% P.S. EFFICIENCY:	79	

TRW SYSTEMS GROUP

FLUID SUBSYSTEM

Fluid movement and pressure throughout the ACPL is controlled by a substantial number of valves and pumps and is monitored by pressure transducers and a relative humidity meter. In addition, the system monitors the states of all valves which are equipped with position contacts. While all set points are controlled by computer, the servo loops (2 valves, 1 pump) close locally. Limited operator control without the computer is possible.

FLUID SUBSYSTEM CONTROL AND DATA

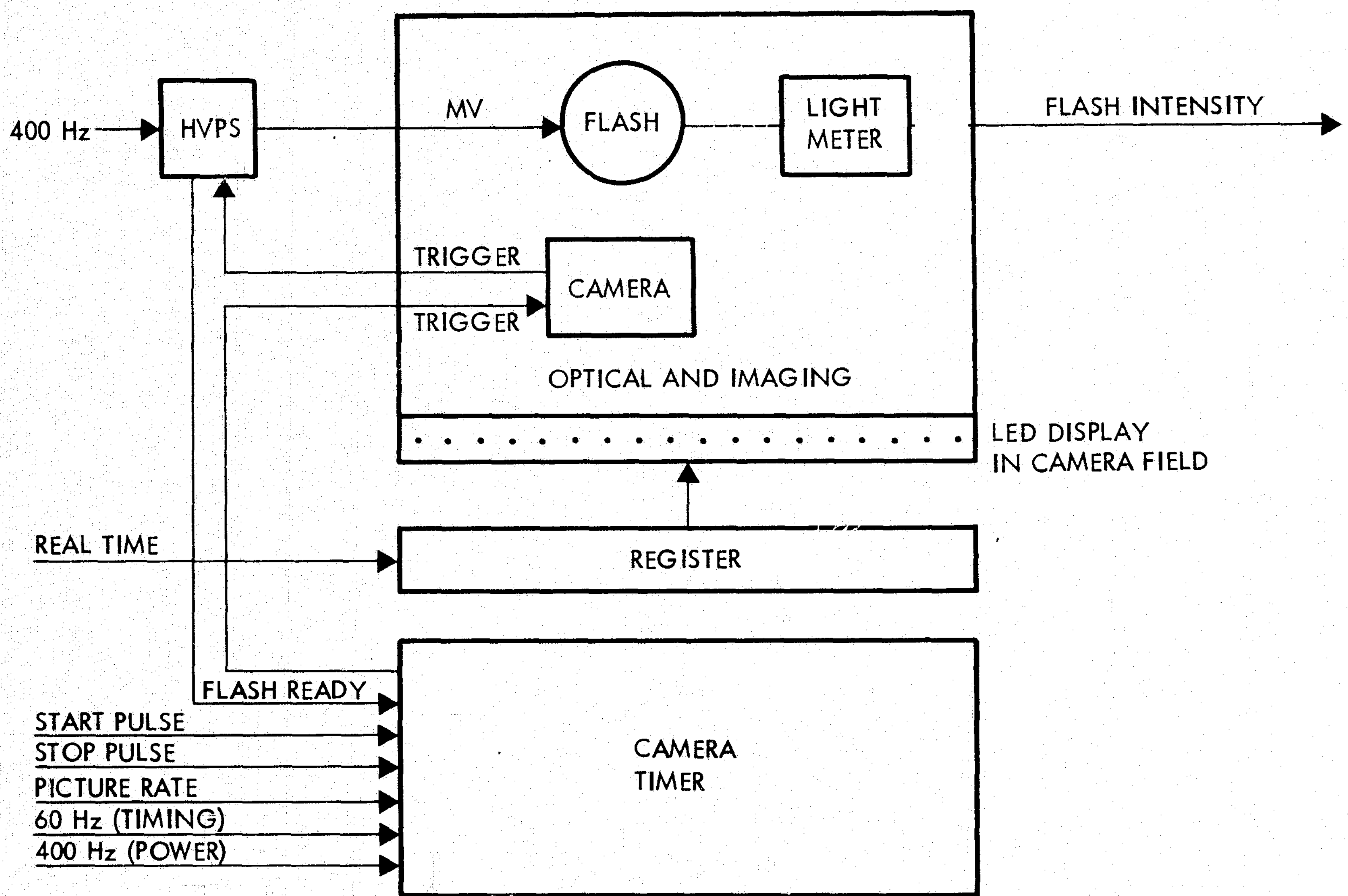


TRW
SYSTEMS GROUP

IMAGING SUBSYSTEM CONTROLS

To facilitate frame rates up to 3 per second, a simple camera timer will be used. Start and stop commands and frame rate can be supplied by computer or operator. To correlate the photographic data with computer stored data, real time is displayed in the camera field of view. The camera will trigger the flash unit. Flash intensity will be telemetered.

OPTICAL AND IMAGING SUBSYSTEM CONTROL

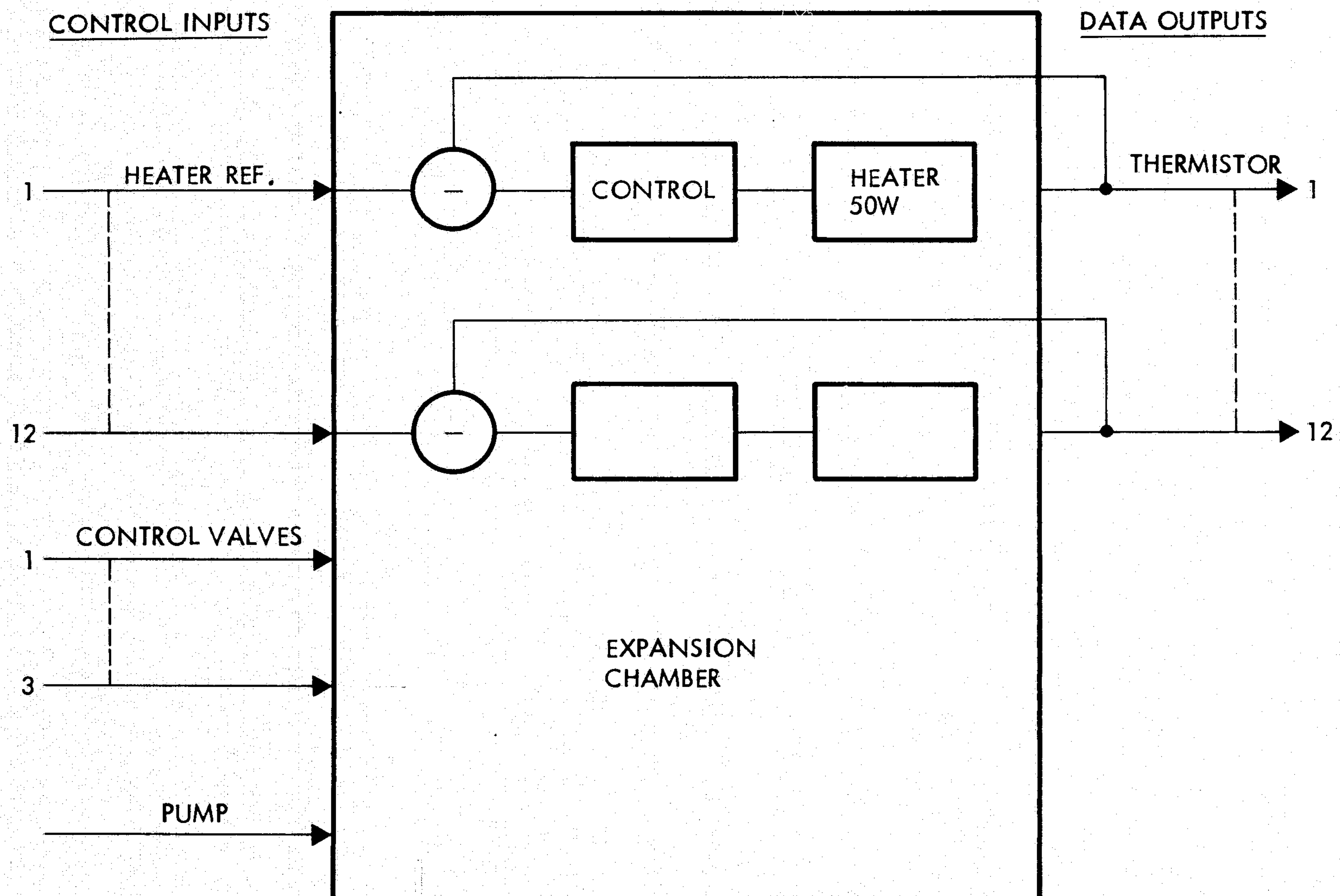


TRW
SYSTEMS GROUP

EXPANSION CHAMBER CONTROLS

The Control subsystem provides the expansion chamber with temperature and pressure controls which facilitate the required or other programmed expansion. Wall temperature is controlled in 12 locations with closed loop heaters. The computer receives temperature data from the thermistor in each loop and supplies temperature set point data which are held by the control subsystem and may be updated once each second. The control loop closes locally. Chamber pressure is controlled by a high and a low capacity pump and by three variable orifice valves which receive control pulses from the computer.

EXPANSION CHAMBER CONTROL AND DATA

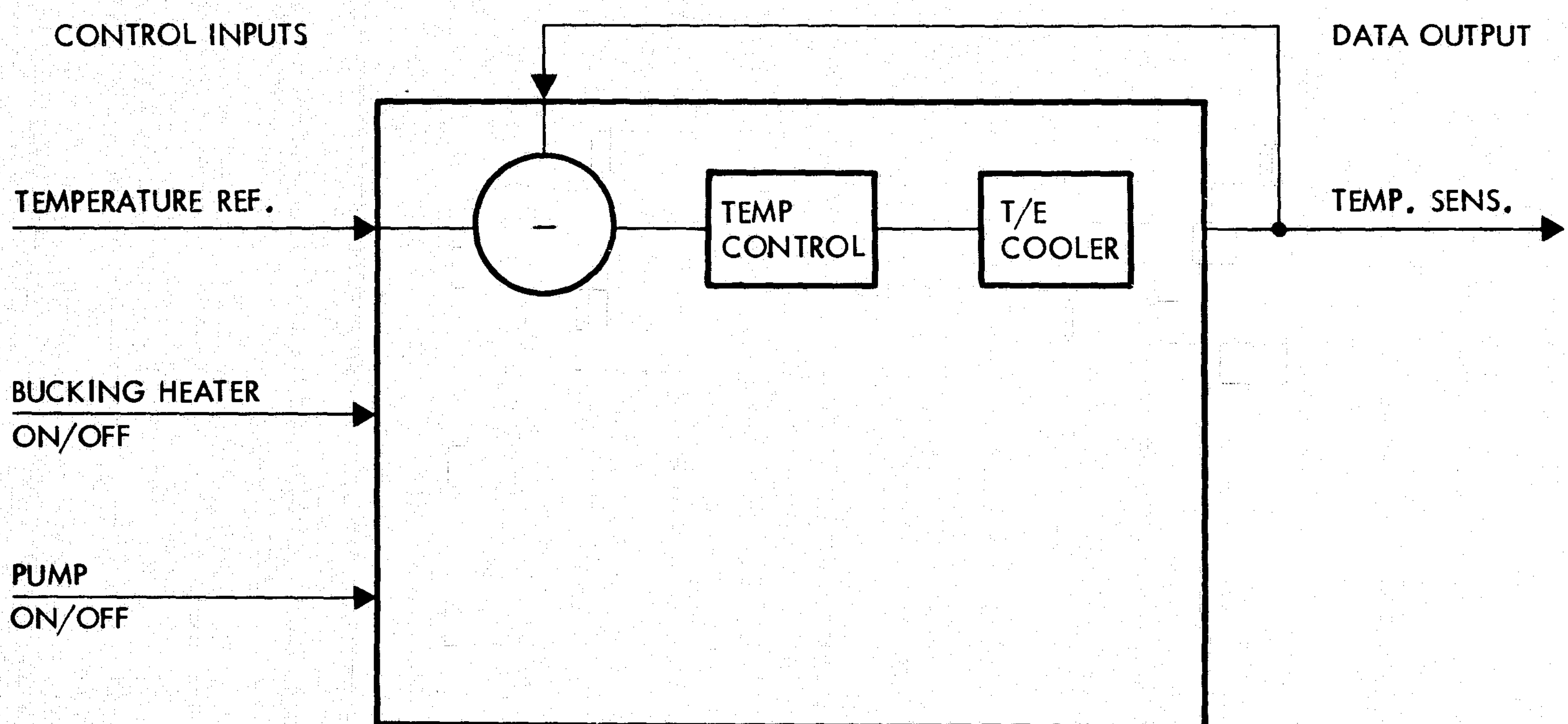


TRW SYSTEMS GROUP

DIFFUSION CHAMBER/HUMIDIFIER

The three diffusion Chambers (CFD 1 & 2, SDL) and the humidifier have similar temperature controls. A thermo-electric cooler is driven by the temperature control circuit. The temperature is measured by thermistor and in a locally closed loop compared with the computer supplied set-point. The set-point is updated at 1 second or greater intervals. A non-variable heater and the input pump are controlled by computer and/or operator.

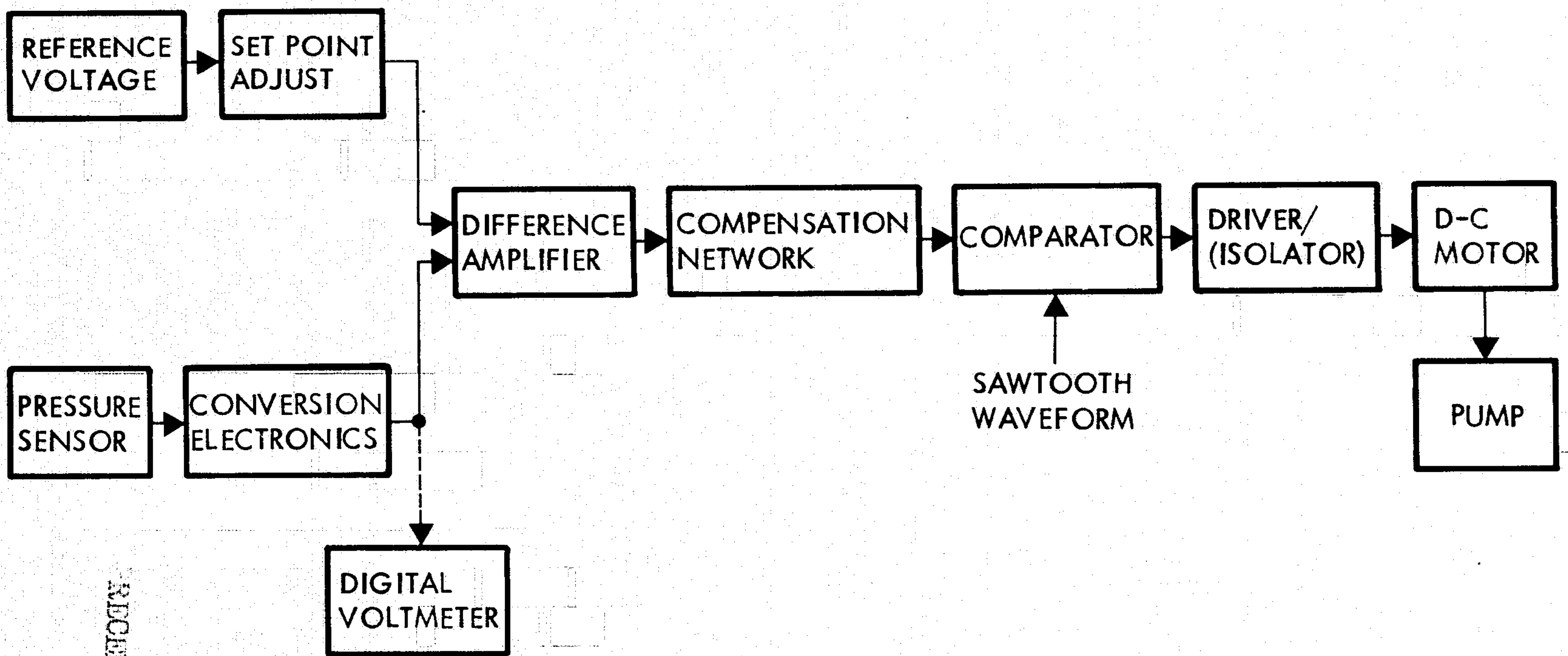
DIFFUSION CHAMBER/SATURATOR CONTROL AND DATA



TEMPERATURE CONTROLS
1. DIFFUSION CHAMBER CFD1
2. DIFFUSION CHAMBER CFD2
3. DIFFUSION CHAMBER SDL1
4. DIFFUSION CHAMBER SDL2
5. SATURATOR

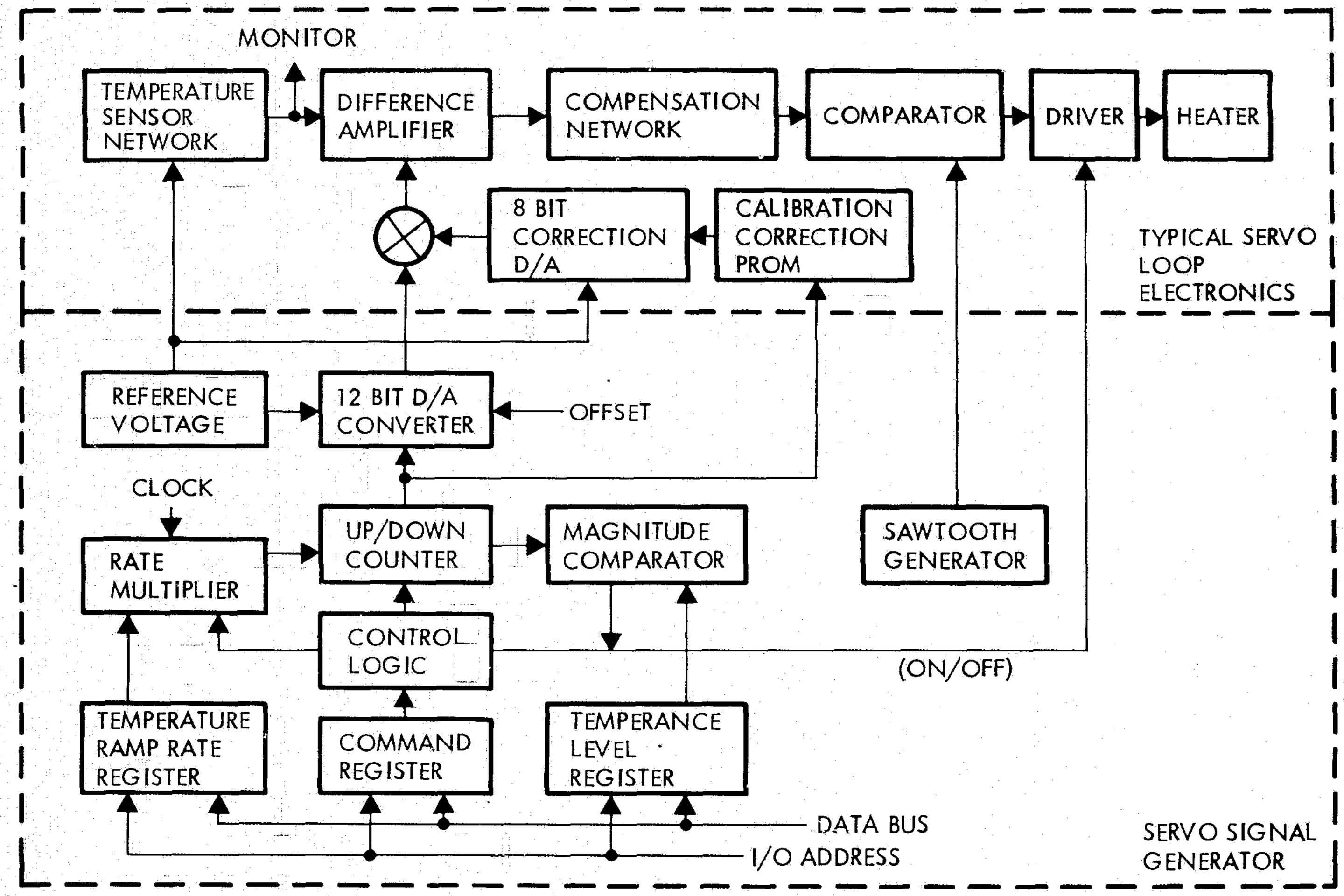
TRW SYSTEMS GROUP

PRESSURE CONTROL ELECTRONICS



- DC MOTOR FOR PUMP SPEED CONTROL
- PULSE WIDTH MODULATED MOTOR DRIVER
- SAWTOOTH WAVEFORM OBTAINED FROM HEATER TEMPERATURE CONTROLLER

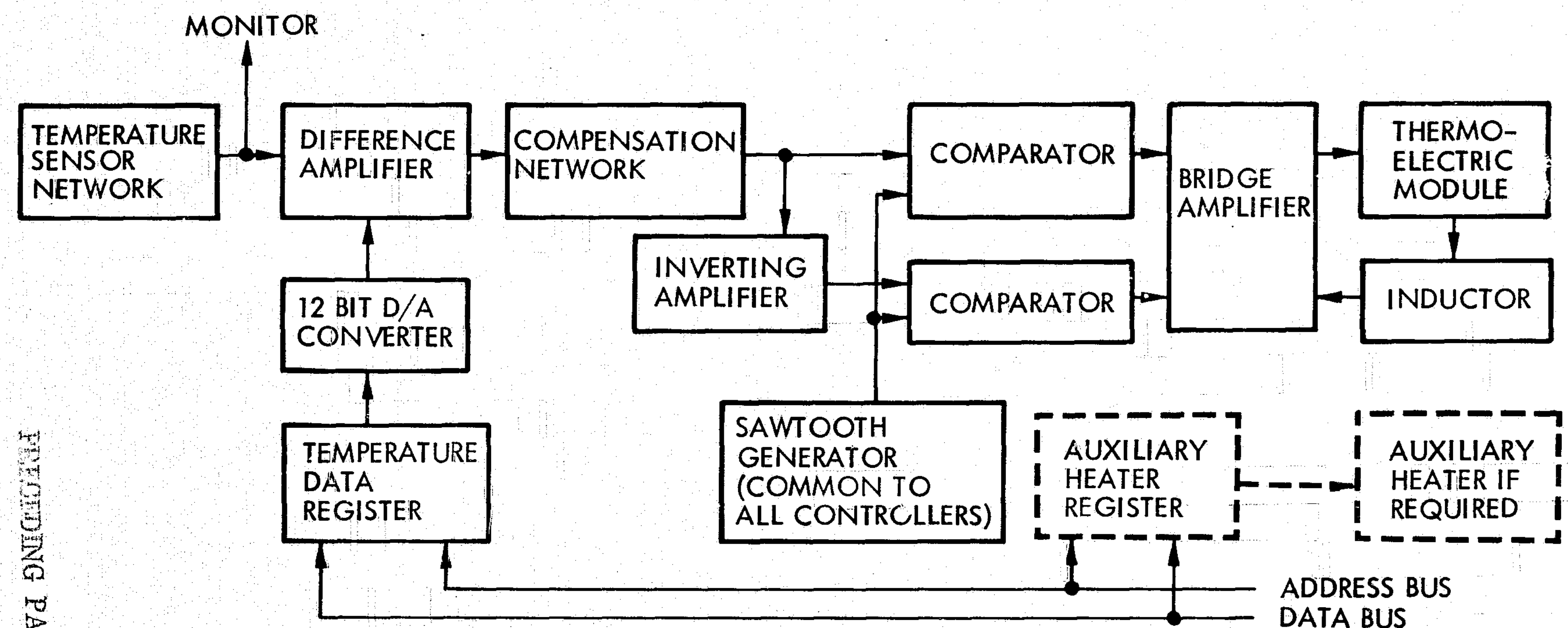
HEATER TEMPERATURE CONTROLLER



- PULSE WIDTH MODULATED HEATER DRIVE
- PROGRAMMABLE TEMPERATURE LEVEL AND RAMP RATE
- INPUT COMMANDS; START/STOP AND HEATER ON/OFF
- QUASI-LINEAR TEMPERATURE SENSOR NETWORK RESPONSE
- CALIBRATION CORRECTION STORED IN PROM
- SIGNAL GENERATOR CAN DRIVE MANY SERVO LOOPS

TRW SYSTEMS GROUP

THERMOELECTRIC MODULE CONTROLLER



- PULSE WIDTH MODULATED HEATING OR COOLING DRIVE TO MINIMIZE POWER
- INDUCTANCE INCLUDED TO MINIMIZE RIPPLE CURRENT
- PROGRAMMABLE TEMPERATURE LEVEL
- AUXILIARY HEATER MIGHT BE REQUIRED TO KEEP STEADY STATE OPERATION OUT OF HEAT/COOL DEADBAND.

SOFTWARE

The software design is based on certain assumptions about:

a) the mode of operation (time-sharing) using the Experiment Computer,

b) services and capabilities provided by the ECOS software,

c) the ACPL control and data subsystem hardware.

ASSUMPTIONS

SPACELAB:

EXPERIMENT COMPUTER - TIME-SHARING MODE

ECOS SOFTWARE PACKAGES - TRIG FUNCTIONS, DDU INTERFACE, FIXED AND FLOATING POINT ARITHMETIC PACKAGES, KEYBOARD INTERPRETER

CDMS DATA ACQUISITION CYCLES - 1 SEC, 100 MSEC, 10 MSEC - PLUS ADDITIONAL REQUESTS (COMPUTER GENERATED)

ACPL PROGRAM STORED ON MMU. OVERLAY OF SEGMENTS AS NEEDED INTO CORE

COMPUTER/ACPL INTERFACE VIA RAU

ACPL HARDWARE:

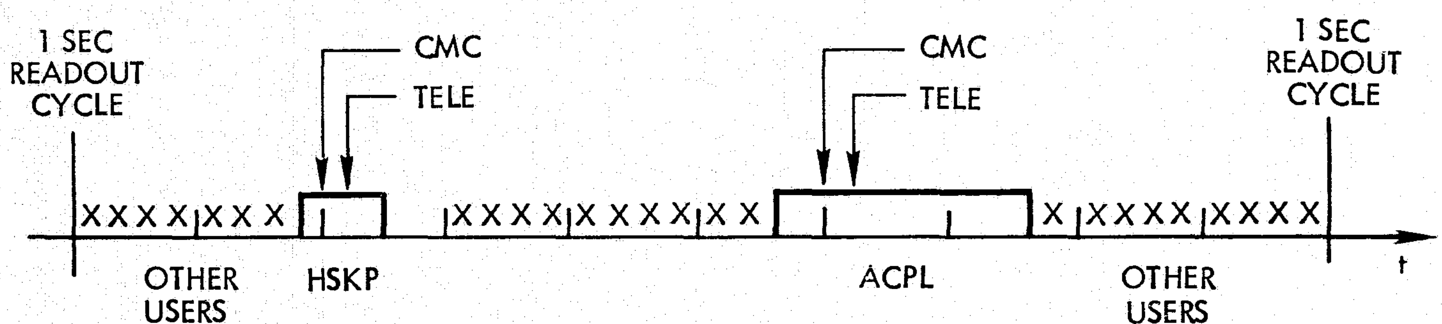
HARDWARE CONTROLLER (E.G., CAMAC)

FEEDBACK LOOPS WITH SETPOINTS COMPUTER SUPPLIED

TRW SYSTEMS GROUP

It is assumed that the ACPL experiment will be run in a time-sharing mode with other spacelab experiments. The ACPL will have use of the spacelab experiment computer during at least two time slots in each timing cycle. These will be used by the main program (ACPL) and by a routine (HSKP) for acquisition and handling of "housekeeping data".

TIME-SHARING OPERATION WITH OTHER USERS



TRW SYSTEMS GROUP

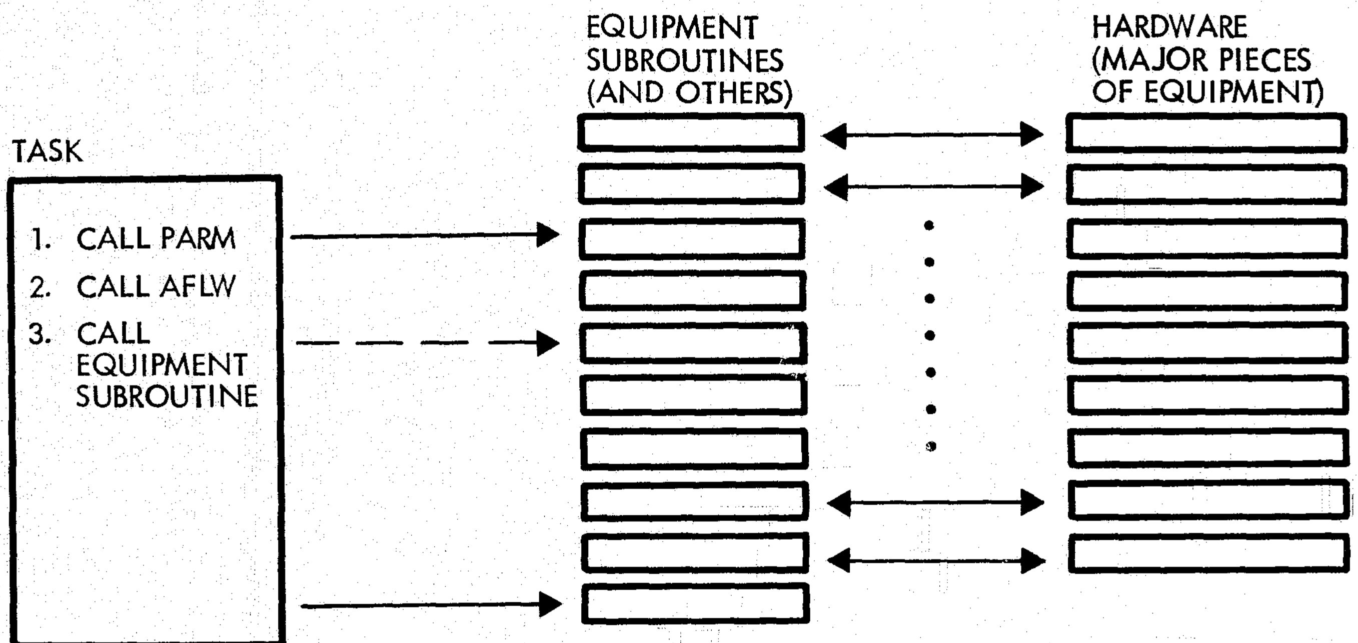
The software consists of a series of subroutines dedicated to specific tasks (basic experiment operations). Within a task there are typically three steps (calls to lower order subroutines):

a) Call Subroutine PARM, which displays parameters for the operation on the DDU screen and allows them to be changed by the operator.

b) Call Subroutine AFLW, which sets up the fluid control subsystem configuration for the particular operation.

c) Call the appropriate equipment subroutine. In general, there is one of these subroutines associated with each ACPL hardware subsystem.

TASK STRUCTURE



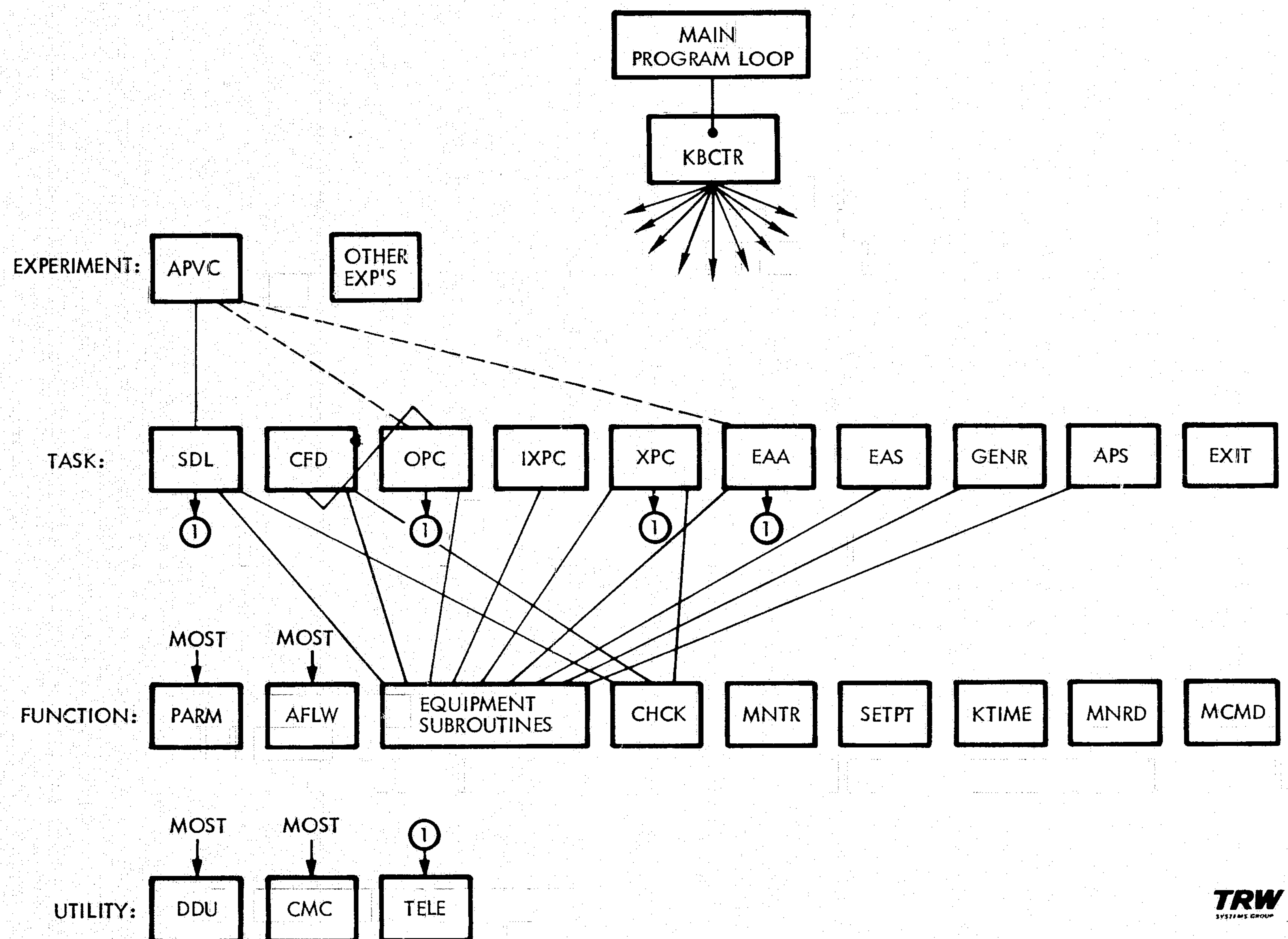
TRW SYSTEMS GROUP

The design on the facing page depicts the organization of the software, and in particular, the interrelationship of the various subroutines.

Computer control resides in the Main Program Loop while awaiting an operator command. An operator request via the keyboard is interpreted by the keyboard control subroutine (KBCTR), which directs program control to the appropriate subroutine.

The remaining subroutines have been assigned, in the diagram, to one of four levels. The operator will usually request a task level subroutine - for a particular experiment operation. This in turn calls function level subroutines PARM, AFLW, and the appropriate equipment subroutine(s). The utility level subroutines interface to the experiment hardware (CAMAC) or to the ECOS software, and will probably be written only in assembly or machine language. Experiment level subroutines involve a combination of two or more tasks.

SOFTWARE ORGANIZATION DIAGRAM

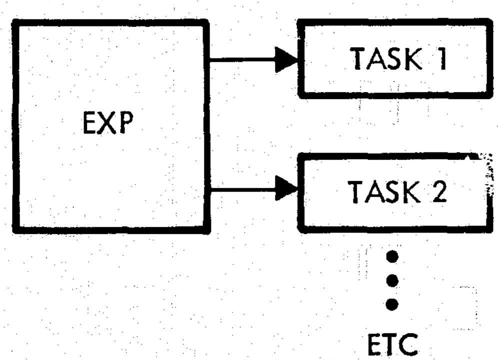


TRW SYSTEMS GROUP

APVC is an example of an experiment level subroutine. It consists of three (3) tasks:

a) Prepare a sample for air purity verification testing (APS)
b) Perform an SDL characterization operation (SDL)
c) Carry out a series of measurements on the sample in either the Optical Particle Counter (OPC) or the Electrical Aerosol Analyzer (EAA)

EXPERIMENT STRUCTURE



APVC
- PARM
- AFLW, APSI ~ TASK 1
- AFLW, SDLI ~ TASK 2
- AFLW, OPCI (OR EAAI) ~ TASK 3

TRW SYSTEMS GROUP

Subroutine SDL is an example of a task level subroutine involving operation of a major piece of equipment (hardware). The operational sequence and software size estimates for this subroutine are shown on the facing page.

SUBROUTINE SDL

OPERATIONAL SEQUENCE:

1. CALL PARM TO DISPLAY/CHECK/CHANGE PARAMETERS
2. CALL AFLW TO CONFIGURE FLUID CONTROL SYSTEM
3. CALL EQUIPMENT SUBROUTINE (SDLI) TO:
   a) MEASURE TEMPERATURE OF ONE PLATE,
   b) USE TO CALCULATE AND SET TEMPERATURE OF OTHER PLATE
   c) CHECK INITIAL CONDITIONS (MEASUREMENTS) TO SEE IF OK TO BEGIN
   d) INSERT SAMPLE INTO CHAMBER
   e) ACTIVATE CAMERA (FRAME RATE CAN VARY WITH TIME)

SOFTWARE REQUIREMENTS:

1. 75 FORTRAN STATEMENTS
2. 285 CORE LOCATIONS

TRW
SYSTEMS GROUP

Subroutine SETPT is an example of a task level subroutine which is not directly associated with any major piece of equipment. The subroutine is used to establish new set points for a series of hardware controllers, according to a list or table stored in the computer memory.

SUBROUTINE SETPT

OPERATIONAL SEQUENCE:

1. ROUTINE IS CALLED WITH AN ACCOMPANYING MODE NUMBER, I.E., CALL SETPT(6)
2. MODE NUMBER IS USED TO SELECT A PARTICULAR LIST OF SET POINTS
3. NEW VALUES ARE WRITTEN IN THE APPROPRIATE SOFTWARE REGISTERS
4. COMMANDS ARE GIVEN TO REWRITE HARDWARE REGISTERS (CAMAC MODULES), THUS CHANGING THE SETPOINTS OF THE FEEDBACK-LOOP CONTROLLERS
5. LIST OF NEW SETPOINTS AND THEIR VALUES IS DISPLAYED ON DDU

SOFTWARE REQUIREMENTS:

1. 25 FORTRAN STATEMENTS
2. 210 CORE LOCATIONS (MOSTLY TABLES OF SET POINTS)

TRW SYSTEMS GROUP

Software size estimates for the major subroutines are given on the opposite page. A 25% contingency has been added to allow for subroutine expansion from the initial estimate.

The number of Fortran statements is used to estimate the effort required to generate the program. The number of core locations includes all array storage associated with a subroutine as well as the number of machine language statements.

Not all segments of the program have to be in core simultaneously. The whole program is stored on the Mass Memory Unit (MMU). Only those subroutines which are actually used in a sequence of operations need be loaded into the overlay area from the MMU.

SOFTWARE SIZE

SUBROUTINE	FORTRAN STATEMENTS (OR EQUIVALENT)	CORE LOCATIONS
SDL	90	330
CFD	40	400
OPC	50	310
IXPC	30	170
XPC	120	670
EAA	80	370
EAS	20	100
GENR	70	300
APS	40	180
PARM	50	190
AFLW	20	170
CHCK	40	120
SETPT	30	210
OTHERS	230	1030
CONTINGENCY (25%)	230	1140
TOTAL	1140	5690

TRW SYSTEMS GROUP

PRECEDING PAGE BLANK NOT FILMED

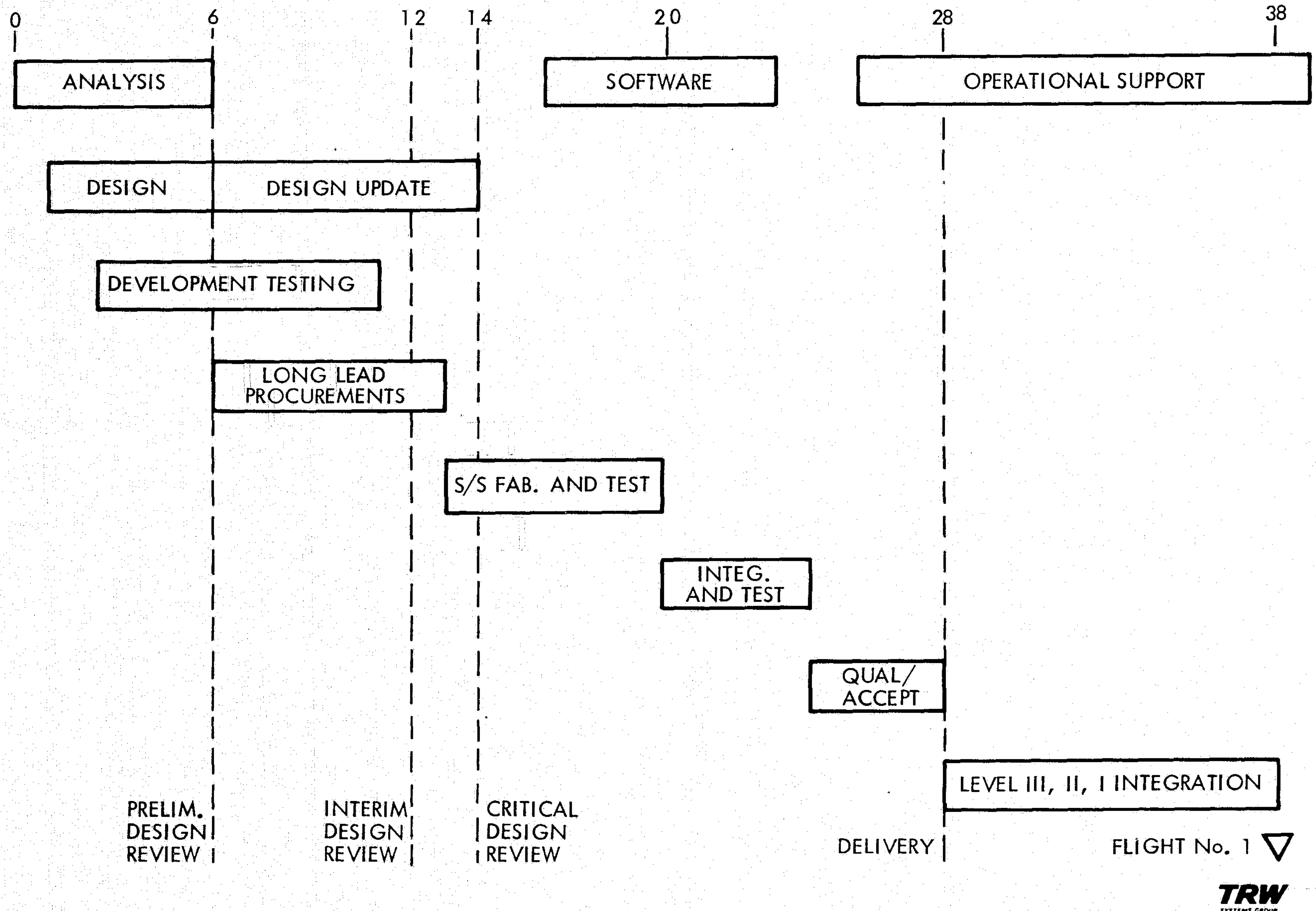
PHASE C/D PROGRAM PLANNING

BILL CLAUSEN

TRW SYSTEMS GROUP

Organization and schedule for the major elements of the initial ACPL Phase C/D program are shown on the facing page from go-ahead through evaluation of engineering data from the first flight. Delivery of the laboratory 28 months after start for integration in Spacelab No. 1 represents an extremely tight schedule which requires careful control of each program element to insure smooth flow from one phase to the next as well as identification of potential problems at a time when they can be worked without impacting program schedule. The tight schedule also demands careful examination of the contribution of each aspect of verification testing to probable mission success.

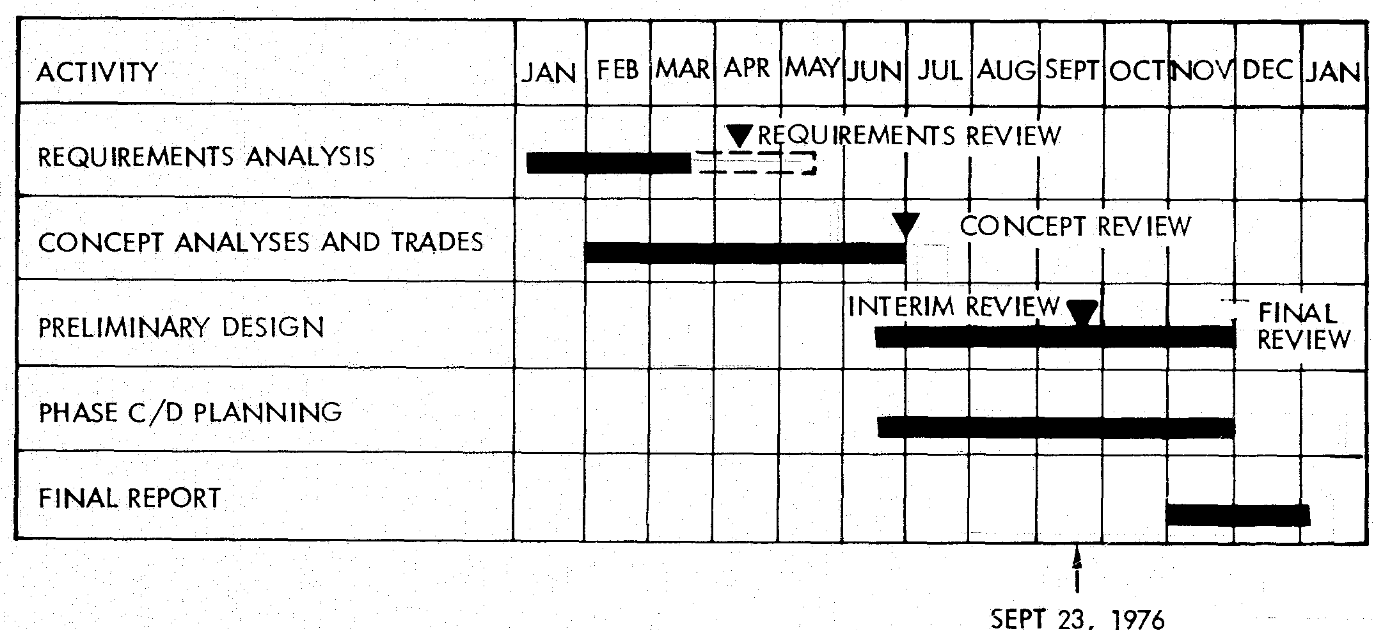
ACPL PHASE C/D PROGRAM SCHEDULE: FLIGHT NO. 1



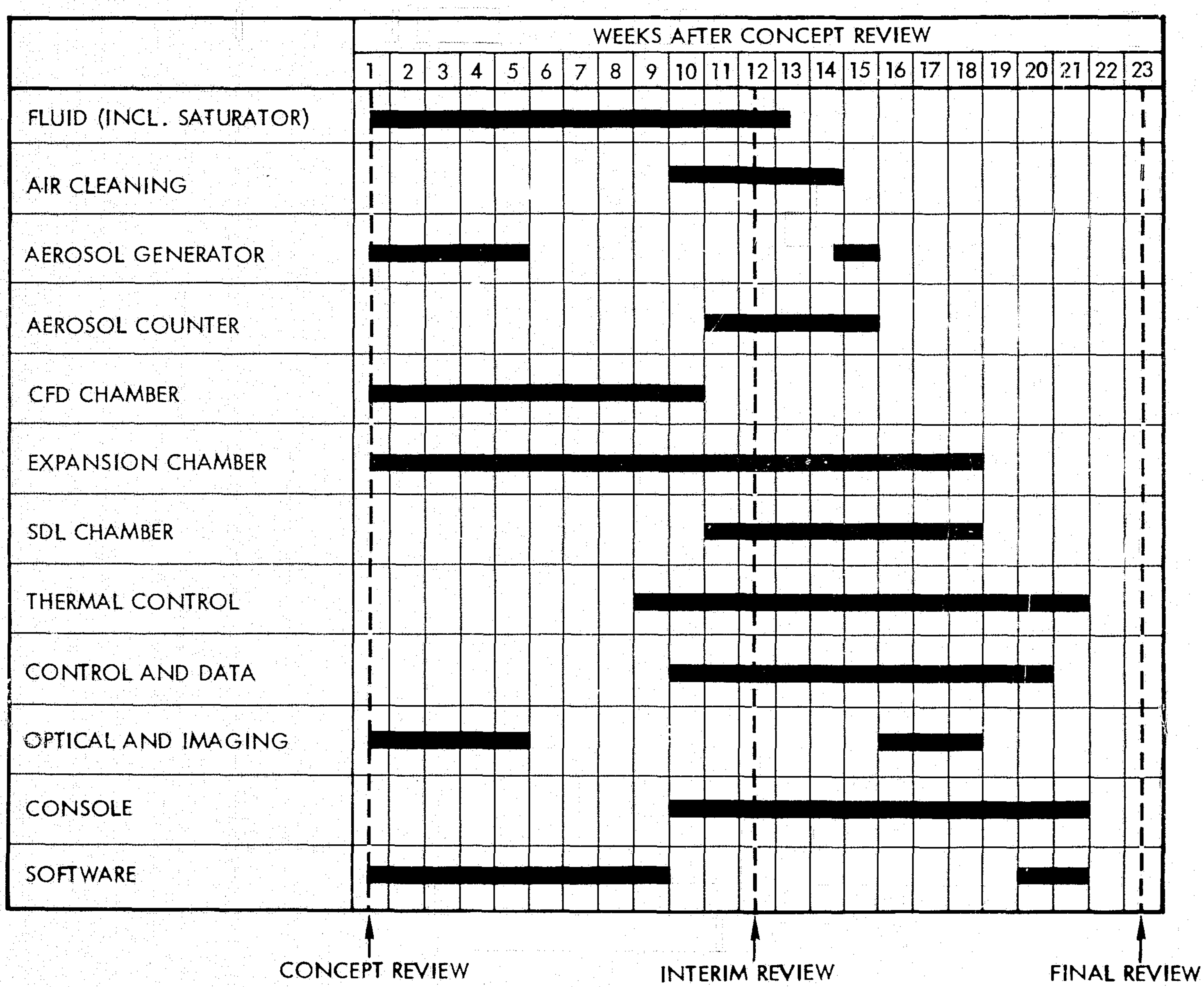
WRAPUP

BILL CLAUSEN

ACPL PROGRAM SCHEDULE



ACPL SUBSYSTEM PRELIMINARY DESIGN SCHEDULE



The Atmospheric Cloud Physics Laboratory, as presently conceived, is a complex system with many technical challenges to be met within the resources available on Spacelab. In our opinion, the single major technical concern deals with the total problem of synchronously cooling the expansion chamber walls. The other technical concerns listed, by comparison, are much less severe.

SUMMARY OF MAJOR TECHNICAL CONCERNS

- SYNCHRONOUS COOLING OF EXPANSION CHAMBER WALLS
- OTHER
  - TEMPERATURE MEASUREMENT
  - UTILIZATION OF SPACELAB RESOURCES (VOLUME, ELECTRICAL POWER)
  - SERVO CONTROL COMPLEXITY

TRW
SYSTEMS GROUP